

ASTRONOMICAL DOCTRINES, &c.

MODERN astronomers seem all to be agreed in opinion that the moon rotates, or turns round on her axis, during the period of her revolution about the earth. They speak of it as an indubitable fact; and, without taking the trouble to examine it, I was induced by their unanimity of opinion, and the authority of their great names, to acquiesce in it as a matter of faith, though inclined to be very sceptical about its truth. Some time ago, however, my attention was accidentally called to this subject, my doubts of its truth became stronger than ever, and I resolved to probe the matter to the bottom. The result is a decided conviction that my faith has been misplaced, and that the moon does not rotate, or turn round on her axis, in the manner alleged. The investigation led me even further than I anticipated; for it suggested a consideration of the established doctrine concerning the sidereal day, and the result of my inquiry into that subject also is the same. The problems are so simple that very few words might suffice to show how they are to be solved; but the received opinions have prevailed so long, and have become so deeply engrained in the minds and systems of astronomers, that it is necessary to examine in detail their arguments and illustrations, in order to show fully and distinctly the nature, the cause, and the absurdity of their errors.

Professor Nichol of Glasgow, in his treatise on "*The phenomena and order of the Solar System*," says, "The moon has one very singular feature, apparently belonging essentially to her as a satellite, since it distinguishes every other satellite with which we are sufficiently acquainted. *She rotates on her axis in the same time in which she revolves in her orbit round the earth*,—in other words, the length of one day and night in that orb is precisely one of our months. The rotations of Jupiter's satellites also nicely correspond with the periods of their revolution around

that planet, and all we know or suspect of the attendants on Saturn is in obedience to the same law. Why this is so is unknown—it is one of those dark points that stir us to profounder inquiry concerning the scheme in which we are; but it is not difficult to trace some of its effects. *Owing to this arrangement the moon always turns the same face towards the earth.* As she goes her monthly rounds, she revolves proportionally on her axis—each spot keeping its relative position towards us; and if it were not that her velocity in her orbit is slightly irregular, we should never see anything of her opposite hemisphere,” p. 159. Other astronomers state the doctrine in very similar terms, but perhaps the best and most explicit expression of the received doctrine of lunar rotation is that given by *M. S. D. Poisson* in his *Traité de Mécanique, 2de édition, Tome II. p. 179–180*, in these words: “Le mouvement de translation peut être revolvutif autour d’un autre corps en repos, ou lui même in mouvement. Il n’y a pas de rotation toutes les fois qu’une face ou une section détermine du mobile reste constamment parallèle à elle même; il y a, au contraire, rotation dans le même temps que la révolution, lorsque le mobile tourne constamment la même face vers le corps central. C’est ce second cas que a lieu dans le mouvement des satellites autour de leurs planètes. La lune tourne toujours la même face vers la terre, et le rayon vecteur qui va du centre de la terre au centre de la lune rencontre toujours en un même point la surface du satellite, d’où il résulte que la rotation de la lune sur elle même, et sa révolution autour de la terre s’achèvent dans un même temps.” “The movement of translation (of a progressing body) may be revolvutif round another body at rest, or itself in motion. *There is no rotation* when one face or a determinate section of the moving body remains constantly parallel to itself; *there is*, on the contrary, *rotation* in the same time as the revolution when the moving body turns constantly the same face towards the central body. This second case is that of the satellites in moving around their primaries. The moon turns always the same face to the earth, and the radius-vector, which connects the earth’s centre with the moon’s, cuts the surface of the satellite always at the same point; whence it results that the moon’s rotation on her own axis, and her revolution about the earth are accomplished in the same time.”

The question at issue is simply this: astronomers say that it is possible for the moon, or any other body revolving in an orbit, to travel round that orbit, and present every part of its circumference in succession to the orbit’s centre, without turning round on its own axis; that the moon, revolving freely in space, should exhibit this phenomenon; but as she does not, and, on the contrary, presents to the earth the same face continually, it

is necessary that to enable her to do so, and *bring* continually the same point *back* to the radius-vector, she must rotate, or turn round once on her axis during each revolution in her orbit, in a direction *contrary* to that of her revolution. In opposition to this, I have seen reason to believe, and shall endeavour to prove, that the alleged presentation of every part of the circumference, *without rotation* or turning round, is impossible; that the shuffling kind of progression to which is ascribed this impossible effect, is a real retro-rotation or turning round on the axis backwards, in a direction really *contrary* to that of the moon's revolution, namely, from east to west; that the rotation which they ascribe to the moon is not "contrary to," but in the *same direction with*, that of her revolution, namely, from west to east; and that, were she to rotate once in that direction during each orbital revolution, the inevitable result of such a rotation would be the presentation, not of the same point continually, but of every part of her circumference in succession to the centre of her orbit. I admit, however, that if the moon were indeed to move freely in space, she would move in the manner they allege, and which I call retro-rotation; and that, as she does not, there must be some power acting against her freedom, and producing the effect of *keeping* the same face continually looking to the earth; but that, whatever may be the nature of that power, its effect is *not to cause* but to *prevent* the moon from rotating "in a direction contrary to that of her revolution;" in short, to keep her from rotating at all. She does, indeed, turn round about in presence of the sun, and *without turning round about* in some way or other, either the moon nor any other body revolving in an orbit could present every part of its circumference as the moon does to the sun or other fixed object, or stationary spectator, outside, or indeed to any other body or spectator whatever; but so far is the moon's turning round from being a revolution of her circumference round about her axis, that, on the contrary, it is the axis itself, carrying the whole mass of her body forward along with it, that virtually revolves about a pivot on the radius-vector, close to the innermost point of circumference, or that point itself, as its centre of revolution. To the sun or other spectator outside, the effect of this kind of revolution is the same as would be the effect of the moon's turning once round on her axis, while remaining at a fixed point of the orbit; but, with respect to the earth or the centre of the orbit, the presentation of every point of the revolving body's circumference without actual rotation or turning round on the axis is impossible, so long as the axis itself revolves at a fixed distance from the centre of its orbit. If, however, the body were to remain at a fixed point, and turn round with its whole mass, including the axis, about that point, as its

centre of revolution, then of course its whole circumference in succession would be presented to the earth as well as to the sun ; but in a regular orbital revolution, as that of the moon or the earth, the presentation of the whole circumference to the orbit's centre, without the revolving body's turning round on its axis, is perfectly impossible. Were a carriage wheel to slide along a rail with the same point of its circumference continually in contact with the rail, would any one ever imagine it was all the time turning round on its axle ? With just as little propriety and show of reason do astronomers affirm that, when the moon slides along the rail of her orbit with the same face continually looking to the earth, she not the less turns round on her axis. For whether the progressive movement be made along a straight line or a curve, the line of motion described by the progressing axis is always and invariably parallel to, or concentric with, the tracks or lines of motion described by the diametrically opposite points of its circumference, each at the angular distance of 90° from those points of circumference intersected by the orbit of the axis and a line drawn through the axis, directly across, and perpendicular to these three lines of motion, and through those diametrically opposite points, will always measure and indicate the body's rotation. Such a line is the radius-vector of the moon or other body revolving in an orbit ; and it is utterly beyond the possibility of any *reasonable* question, that a revolving body which keeps the same point of its circumference continually attached to the radius-vector, in precisely the same relation to the axis and all these other points, must revolve without rotating or turning round on its axis. It is, indeed, nothing less than a positive contradiction in terms to say that the moon *rotates*, when as admitted, she really *does not turn round about on her track like a wheel* ; for, without turning round about on her track *like a wheel*, she cannot turn round about on her axis. The one is the indispensable condition and accompaniment of the other.

Dr Johnson defines "rotation" to be "the act of whirling round like a wheel ; the state of being so whirled round ; whirl vicissitude of succession." Well ; how do the phenomena of the moon's motion correspond with these definitions ? She presents continually the same face to the centre of her orbit ; and astronomers allege that phenomenon to be the effect of her *rotation*, or whirling round like a wheel on her axis *once* during the period of her orbital revolution ; but, strange to say, this alleged rotation, or whirling round, so far from producing a "vicissitude of succession" in respect of the fixed centre of her orbit, leaves the same point of circumference constantly in the same relative place towards that centre, just as if there were no rotation or whirling at all. The moon maintains precisely the same rel-

tion to her orbit and its centre, no part of her circumference passing the one or crossing the other during the whole revolution, so as to shew the indispensable signs of rotation, or whirling round on an axis. And to make the matter worse, it is alleged that every "vicissitude of succession" in the parts of the moon's circumference, with respect to the earth, might be produced *without rotation*, thereby completely confounding and running counter to the great lexicographer's definition, as well as to common sense. By "rotation," or turning round on an axis, is universally understood to be meant the fact of a body's moving all the parts of its circumference round about an axis within itself, presenting them all in succession on every side of that axis, and making them all in their turn pass a straight line, real or imaginary, connecting that axis with a given point outside, perpendicular to the body's line of motion; or, in other words, crossing the line of motion at right angles; such as, in the moon's case, the radius-vector that connects her axis with the centre of her orbit, and which, if her orbit were a perfect circle, would be always perpendicular to her line of motion, and cross her orbit at right angles, at whatever point of that orbit the moon might be for the time; or, as in the case of a common wheel, a rod crossing it diametrically, perpendicular to the road or rail along which it is moving, or a wheel moving in a frame with which its axis is connected by a cross bar. But, when the moon *rotates*, as is maintained, so far is she from moving all the parts of her circumference round about her axis, presenting them all in turn on every side of that axis, and making them in succession pass her radius-vector or cross-bar, that, on the contrary, she keeps them all invariably on the same side of her axis, and the same three points of her circumference severally attached to the radius-vector, and to the orbit at either side, 90° from that radius; while the inner end of the radius-vector is virtually attached to a fixed point which never changes its place, so far at least as the moon is concerned. If the radius were loose, so as to be at liberty to move past the orbit's centre, it might be considered as virtually a portion of the moon's substance, and consequently as partaking of all the moon's movements; and, in that case, there might be some show, but only a show, of truth in the allegation. But when it is considered that the radius is, on the contrary, virtually a part of the centre of the orbit itself, merely an extension or expansion of that centre, and nothing more than the representative of the several points of its circumference in succession at the place where the moon passes them, even the show of truth is gone, and the doctrine stands forth in its glaring absurdity. Moreover, astronomers affirm, that if the moon were to move the parts of her circumference backwards, or from east to west, across the orbit outwards in that direction,

and back again on her other side, presenting them all in their turn on every side of her axis, and making them all in succession pass her radius-vector, thereby exhibiting to the earth a complete "vicissitude of succession," and all the signs of rotation, or whirling round on an axis, all this would or might be produced without rotation, or turning, or whirling round! It is also stated, that not only the middle point of that side of the moon which is always looking to the earth, but also the radius-vector and *the earth itself*, or at least "its visual ray," which is the same thing, revolve (that is, move in an orbit, or describe a circle,) round about the moon's centre, while that very centre itself is revolving about the earth! Paradoxical as such doctrine seems, and well calculated as it is to startle and surprise, and provoke to scrutiny, it has nevertheless kept its ground for two centuries, and received the solemn sanction of the great minds of whose achievements astronomy so proudly boasts. But how will unscientific readers be amazed to be told that all these paradoxes are founded on no less monstrous an assumption, than that it is the property of the centre of a circle not only to change its place continually within the circle, but even to rotate or go round about the axis of a body moving along the circle's circumference, yet *without going out of the circle*, which one would think an indispensable requisite to enable it to perform that rotation! Without this fundamental proposition to rest on, the doctrines of the moon's rotation, and of the sidereal day's being the true measure of the earth's rotation cannot subsist a moment. This will be best accomplished, perhaps, by stating the simple truth, which must at once receive the assent of those who examine the question, even though they be told at the same time that the opposite error has been expressly affirmed by Galileo and La Place, sanctioned by Newton, and tacitly at least, perhaps inadvertently, admitted by all other astronomers, as an established truth in their science.

The centre of a circle, considered in relation to the circle itself, is a fixed point, which remains invariably in the same place, equidistant from every point of the whole circumference; and, consequently, every radius, or straight line drawn from the centre to the circumference, will be invariably of the same length, and cut or touch the circumference at right angles.

From this it follows obviously that every point of the circumference, and all the points together, whether limited in number, or infinitely numerous, will bear precisely the same relation to the centre. Each of them will occupy the intersection of two lines crossing at right angles, or perpendicular to each other, namely, the radius that connects it with the centre, and the circumference itself, of which it forms a part.

The centre of a circle is, by the necessity of its nature as such,

incapable of changing its place within the circle, and, consequently, maintains invariably the same relation to every part of the circle and its circumference, and to every body, axis, or mathematical point, moving about on that circumference. At whatever point of the circumference the revolving axis may be; however much it may vary its relations to objects outside, *its relation to the centre is invariable*, namely, it is always at the outer end of the shortest straight line that can be drawn between it and the centre, and which straight line, invariably perpendicular to the circumference of a perfect circle, is its radius-vector. Each of the radii also, whether considered as lines in the substance, or on the flat surface of the circle, including the fitting radius-vector itself, is by the same necessity of its nature as the radius of a circle, just as incapable as the centre itself of changing its angular relation to the circumference and the centre, and remains invariably the shortest straight line between them at any given point. Whatever, therefore, can be truly predicated of any movement or event taking place at the outer end of any one radius, would be just as truly predicated of the same or a similar movement or event if it were to happen at the circumference, at the outer end of any other radius, or proportionally at the outer end of each of them in succession.

When a round body, as a globe or wheel, moves forward in space, the direction of its line of motion is indicated by a line, straight or curved as the case may be, passing through its axis, parallel to, or concentric with, the road, rail, or mathematical line traced by either side of its circumference; and if it rotate or turn round on its axis, the rotation is indicated by the passage of every point of its circumference in succession past that line of motion, and also past another line drawn perpendicularly to the line of motion, and which perpendicular line, in the case of orbital progression and revolution, is the radius-vector, virtually identical with any one, and with all in their turn, of the fixed radii of the orbit, and as incapable, by the necessity of its nature, as any one of the fixed radii themselves, which it successively represents, of turning round about on the axis of the revolving body. If, on the contrary, no part of the revolving body's circumference pass the radius-vector and the line of motion, the same respective points remaining continually in one with one or other of these lines without any change of their relation to either of the lines, then it cannot be more certain that the sun and the moon revolve, or seem to revolve, about the whole heavens, than that a body so remaining unchanged in all its relations to its own line of motion and radius-vector, progresses without turning round on its axis. The moon, however, by the admission and declaration of all the astronomers of the last two centuries, revolves in her orbit precisely in these circumstances; that is, with-

out carrying the points of her circumference in succession past her radius-vector, and across the line of motion described by her axis, and, consequently, keeping the same face continually looking to the earth, and very nearly the same visible points of her circumference continually in one with her radius-vector; and no logic can evade the conclusion, deduced from the very nature and circumstances of all rotation, that she revolves in her orbit *without turning round on her axis*.

The radius-vector of a planet, or other body moving round an orbit, may be considered in two points of view: either as a constituent and substantive part of the orbit itself, or of its centre, or as a constituent and substantive part of a body revolving in contact with the centre of its orbit. In the former case, the radius-vector is virtually a rod attached by a hinge or ligature to the centre of the orbit, or, more correctly still, it is virtually a line drawn on the surface of a disk co-extensive with the orbit, and consequently capable of making no more than one revolution round only one of its ends at once; and the end round which only it is possible for it to revolve is the one attached to the centre of the orbit, and no more movable from its place than the centre itself is. And, in performing that single revolution of which alone it is capable, each of the points of which every radius is composed moves with different degrees of velocity, proportional to its distance from the centre, and all these points moving together describe a series of concentric circles, increasing in dimensions as they go outwards. Consequently, all the points move through unequal spaces in equal times; and the result is, that, while the innermost points describe an invisible circle round an invisible point, all the other points describe always increasing circles round that point as well as the centre; whereas, on the contrary, according to the astronomical doctrine I am combating each of these points describes a circle, *not round the centre itself but round the outer end of the radius of which it forms a part* while that outer end, and that only, by itself, describes a single circle round the centre of the orbit.

In the other point of view, the radius-vector may be considered as a part of the revolving body, and to represent by its inner end the circumference of a circle as large as the orbit itself, but only half within the orbit, and having the axis of the revolving body for its centre. But it is obvious that the radius-vector so circumstanced, so long as it remains attached to the orbit's centre, can no more revolve about its outer end, or the axis of the revolving body, than any of the radii of the solid disk we have been considering, or than the centre itself; and, consequently the point of the revolving body's circumference that remains always in one with the radius, can no more revolve about the axis

than the radius which accompanies it; and, on the contrary, were that point of circumference really to revolve about the body's axis, accompanied by the radius-vector, the indispensable condition of such a revolution would be the setting of the radius-vector free from its attachment to the orbit's centre, and then its inner point, so set free, would be seen moving away from the centre to the outside of the orbit, and back again, just as often as the body turned round on its axis, whether that happened *once* only, or twice, or a thousand times during a single revolution in its orbit.

But the radius-vector is not a material vinculum capable of being thus detached and moving away from the centre. It is merely a mathematical or imaginary line, forming the shortest straight line between the revolving body's centre and the centre of the orbit; and this character it preserves at every point all round the orbit's circumference. But these points of circumference remain invariably at the same distance from the centre; and the centre or axis of the revolving body has precisely the same relation to that centre as the point of the orbit which it may occupy for the time, so that its radius-vector is successively identical with, or occupies precisely the same place as, the radii one after another of the points which it passes, and is consequently invariably perpendicular to the planet's line of motion, or the orbit which the planet's axis describes; and round that axis it could not revolve without losing its perpendicularity, and ceasing to be the radius-vector, or, simply, could not revolve at all. If a material vinculum, acting as a radius-vector, were to be set free from attachment to the orbit's centre, it would then become virtually an outlying arm of the planet itself, partaking of all its movements, whether of orbital revolution or rotation; whereas, on the contrary, the true radius-vector, by the necessity of its nature as such, takes part in the orbital revolution only, and is never, and cannot be, in the slightest degree affected by the planet's rotation on its own axis. The true immaterial radius-vector remains invariably, in all circumstances, the shortest straight line between the revolving axis and the immovable centre round which it revolves. It follows of course the forward movement of the revolving axis, but never does nor can revolve about it, any more than the centre itself of the orbit, which is certainly fixed in its place and immovable. If, then, the inviolable rectangular radius-vector cut invariably the same point of the planet's circumference, that of itself is the most direct, the surest, and the most incontrovertible proof that the revolving body does not turn round on its own axis; for to say that it does so, in such circumstances, is no less preposterous than to uphold that the immovable centre of the orbit leaves its place, and

revolves round about the moving axis, at the very time that axis is revolving about the centre itself.

The axis of a revolving body remains constantly at the same distance from the centre of its orbit, and the radius-vector is always the shortest straight line between that axis and that centre. But the radius-vector has only *one* movement, always *forwards* with the moving axis which it connects with the immovable centre, its different parts moving with different degrees of velocity proportional to their distance from the centre. It never *turns back* its inner end any more than the centre itself to which it is attached turns back from its central position, and consequently every change that takes place in the relation of the parts of the moon's mass or circumference to that radius can only be the effect of movement in the moon itself or its parts. The relation of the radius-vector to the moon's axis is invariable; and if the same point of the moon's circumference be always intersected by the radius, the relative position of that point not only to the radius, but also to the axis of the moon and to the centre of the orbit, must be just as invariable as the invariable and immovable centre itself. It will always keep the same relative place on the shortest straight line between the axis and the centre, being itself the nearest point of the revolving body to that centre; and there is only one way in which its relative position can be changed, namely, by its diverging from the radius-vector, either to the right hand or to the left. In either case the moon's mass will oscillate, or turn on its axis, to the extent of the divergence, and if the divergence be continued in either direction till every point of the circumference in succession shall have passed the radius-vector, the body will have performed a complete rotation on its own axis, whatever may be the phenomena or appearances which it may present in other respects. The passing of all its points across the radius-vector is the surest, as it is indeed the most perfectly incontrovertible sign and proof of its rotation.

The radius-vector certainly does not cross the orbit with it; the inner end of the radius-vector, which, I may say again, is nothing else than the shortest straight line betwixt the moon's axis and the centre of the earth, certainly *does not revolve* in the opposite direction round about on its outer end at the moon's axis, unless it were true, what is, however, positively and perfectly impossible, that the fixed centre itself revolves about the moon and her axis. How, then, is it possible to avoid the conclusion that, if the moon were to revolve with all the points of her circumference in succession *passing the radius-vector and crossing the orbit*, though she might at the sametime keep the same face constantly looking to the same fixed point outside; or, in other words, supposing her to move in or on a horizontal plane with the north, south, east, and west quarter points of her circumference always directed, each

to the corresponding point of the horizon, she could only accomplish that feat by means of a rotation, or turning round on her axis *once*, during the period of her orbital revolution? In such a case, one of two things must happen; either the point of the revolving body that diverges from the radius-vector westward turns round on the body's axis 90° in each quadrant, or the centre of the orbit, carrying the inner end of the radius-vector along with it, turns round about the body's axis to that extent in the contrary direction. But the centre is a fixed spot, which, by the necessity of its nature as a centre, is incapable of moving from its place; the radius-vector, proceeding from that centre, is by its nature just as incapable as the centre itself of turning backwards by its inner end; while, on the contrary, not only is there no incapability of movement on the part of the planet, but there has been a real and visible movement of the parts of its circumference, past and away from the radius-vector and the centre and across the orbit; therefore, it follows inevitably, that the divergence to be accounted for is and can only be the effect of the last mentioned movement of the planet, and of a real and actual rotation, or turning round, of the body on its axis.

From these premises it follows inevitably that whensoever, and to whatsoever extent there happens a change of relations between the parts and points of circumference of a body revolving in an orbit, or circular path, on the one side, and the radius-vector or other radius, or radii of the circle and its centre, on the other, that change must be the result, solely and exclusively, of a rotary movement of the revolving body on its own axis. For example, suppose a disk to be placed at the north point of an orbit, and to turn once round on its own axis at that point, every point of its circumference in succession would be seen to pass the radius-vector, till they had all completed a rotation about the axis, the point that first diverged from the radius on the one side being the last to return to it on the other. But if, instead of completing the rotation at N, the planet were to rotate to the amount of just one degree of its orbit, the result would necessarily be precisely the same, so far as respects the radius-vector, and the invariable centre which the radius everywhere represents; and that, whether the rotation be from west to east, or from east to west. If a cord were attached to the circumference of the disk and to the centre of the orbit, it would be carried round about the axis precisely in the same way, whether the rotation were performed all at once at N, or only gradually during the revolution; and such perfect sameness of effect can only be reasonably ascribed to sameness of cause. When, therefore, the planet moves one degree, and each point of her circumference at the same time diverges one degree from the radius, that divergence

is the infallible sign of the planet's rotation, and the invariably perpendicular radius-vector is the fixed point where the rotation begins and ends. If the rotation be made in the same direction as the orbital revolution, or from west to east, to the extent of one degree of circumference for each degree of the orbit, the planet will, in every complete orbital revolution, inevitably bring every point of its circumference in succession once to the radius-vector, and there present it directly to the centre; and from this undeniable fact it follows inevitably that if the same point of circumference remains continually in one with the radius-vector, and directed to the centre, that permanence of its relation to these members of the orbit, which are in themselves invariable in their relations to the planet's axis, must be, and *is*, the certain token of the planet's *non-rotation*.

But, as astronomers say, if the moon were *not to rotate* on her axis, she would carry every point of her circumference in turn past the radius-vector, backwards, or from east to west, and present them all in turn to the earth in or near the centre of her orbit, and, at the same time, keep all her parts perfectly parallel to a fixed straight line drawn across the plane of her orbit, and that permanent parallelism is a proof of her non-rotation. The moon would, indeed, if she were perfectly *free* in her movements, under the single condition of keeping her *axis* within the limits of a definite orbit, exhibit these phenomena, and preserve that perfect parallelism; but, *horresco referens*, that would most certainly be the effect of her rotation on her axis backwards, or in a direction *contrary* to that of her revolution, namely, from east to west, while she revolves from west to east. And to keep in countenance this paradox, it is assumed, not tacitly or inadvertently, but directly and expressly, that, in this case of retro-rotation, or so-called parallelism, it is the radius-vector, nay, the centre of the orbit itself, that moves in the opposite direction from the point *a* of the moon's circumference! But I have endeavoured to show already, that the radius-vector and the centre are perfectly incapable, by their very nature as such, of making the smallest change in their relations to the moving body; and that, whatever change takes place in the relations of the moving body's circumference, is, and must be, solely and exclusively the effect of the rotary movement of the planet, or satellite on its own axis. And the parallelism which has been assumed, and so triumphantly referred to as the token of non-rotation, would be occasioned by so very simple a process as this. When the planet turns round on its axis from east to west, the axis itself, while it preserves the same invariable relations to the radius-vector and the centre, is continually changing its place on the orbit, and of course its relations to every surround-

ing object, outside of the orbit, all round the compass ; and, as the rotation is performed in precisely the same proportion as the orbital revolution, degree for degree, but in opposite directions, the result is *apparently*, though not *really*, to neutralize the rotation, and so to keep the parts of its mass always directed to the same points of the compass, always parallel to themselves, and to a fixed straight line drawn in the plane of the orbit.

A planet, moon, or other round body revolving in an orbit has a certain definite breadth or thickness, and the orbits or circles described by the different parts of its mass are consequently of different dimensions, proportional to their radial or diametric distances from the orbit's centre. The innermost point of circumference *a*, will describe an orbit *less* than the orbit described by the body's central axis *c*, by the amount of the measure of one circumference of the body, while *c* will, in its turn, describe an orbit also one circumference *less* than the orbit described by the outermost point of circumference *b*. Thus, when the body revolves without rotating, *b* will be found to travel the measure of *two* circumferences, and *c* *one* circumference, more than *a*. When, therefore, *a* diverges from the radius-vector to the left, and turns round about the axis from east to west, returning to the radius-vector from the right, it travels, by virtue of such rotation, just the measure of *one* circumference more than the length of its own proper orbit, and consequently through a measured space, or along a measured line, precisely equal to the dimensions of *c*'s orbit ; and in no other way, and by no other means than rotation round *c*, could it accomplish such a feat. In the meantime, however, *b*, and the succeeding points of circumference, which all take the outmost place in their turn, have travelled the measure of one circumference more than *c*, and consequently more than *a* likewise ; and that additional length of the outermost point's journey, has the effect of making both *a* and *c*, as well as *b* itself, preserve the parallelism referred to, while not the less *a*'s rotation on the axis is a *real* and *actual* event ; there being the measure of *two* circumferences travelled by the outermost point to be met by only *one* circumference in excess on *a*'s part, and consequently there being that space available for the purpose of keeping *a* always in the same parallelism, and *apparently* without rotation ; but such an *appearance* can deceive only those who *neglect* to inquire into, or who *wilfully overlook*, its cause. All the three points, *a*, *b*, and *c*, will be found in this case to have travelled precisely the same measured length of space in the same time, and *rotation on the axis c*, is the indispensable means of producing such an equality in the rate of movement. If, on the contrary, there be no rotation, the point *a* will remain constantly in one with the radius,

and a , c , and b will revolve in three concentric orbits, at different distances, and with different velocities, proportional to these distances, b travelling one circumference more than c , and *two* circumferences more than a , while c will also travel *one* circumference more than a , and *one* less than b . And this is the *real* and very simple and obvious cause of the parallelism. The point b , as a part of the circumference, rotates backwards as well as a , and by so retro-rotating loses the value of *one* circumference in its orbital journey, while a gains one; but b 's place on the outermost circle or orbit is continually supplied by the other points of circumference in succession, including a itself in its turn, at the 180th degree of the revolution; and the combined gain of these points altogether is just that *one* measure of circumference which serves to maintain the parallelism.

It must be obvious, from the least consideration of the circumstances, that the outermost point of the revolving body's circumference, whether it be a fixed point, as in the moon's case, or a continually changing point as in the case of the earth, must necessarily describe a larger orbit than the innermost point; so that, whether the body rotate on its axis or not, the outermost half of its mass will move through space with a greater velocity than the innermost half, or, which is the same thing, than the central axis, in the proportion of one circumference more than the length of the orbit which the axis describes; and the effect of this surplus movement is, that, if the body rotate on its axis *once* during the orbital revolution, it will present every point of its circumference in succession *twice* to every fixed object outside, *one* of these presentations being the effect of rotation on the axis, and *the other* being the effect of the superior velocity of the outer half of the mass, that superior velocity itself being directly the effect of the constrained movement of the axis, in obedience to the centripetal force which keeps it in its orbit. When the body revolves without rotating, the same point of circumference will remain continually in one with the radius, on the same side of the axis, and on the *inside* of the orbit, without the slightest variation in its relation either to these members of the circle, or to its centre, but will present every point of its circumference in succession *once* to every fixed object outside, and that by virtue of the superior velocity of the outer half of the mass, which proceeds during the revolution, without affecting the rotation on the axis. Let the diagram (Fig. 1) represent the moon as at each of her quarters; and suppose that she, without quitting these points, turns round on her axis 90° at each. At north, the point a will be facing the earth; but, by turning round 90° , there a will get into the line of the orbit, 90° from the radius-vector as at W. At W., a will turn away other 90° , and will then

be distant from its first position by the whole length of the moon's diameter, as shown at S. At S., *a* will again turn round the third quarter of 90° , and get into the position shown at E. At E., *a* will turn round its fourth quarter of 90° , and get into the position shown at N. In these quarter points *a* could get into the several positions it occupies in no other way than by the moon's retro-rotating, or turning round on her axis backwards, in the direction from east to west; and if this retro-rotation were to happen 360 times, instead of only four, as in the diagram, why should not a turning away of her circumference to the extent of one degree of the circle of rotation be allowed to happen at each of these 360 points, as well as a turning away to the extent of 90° at each of the cardinal quarter points, and with the same result, namely, *a* remaining always looking south?

With respect to a revolving body, all the results of her orbital revolution, and self-rotation during that revolution, would be most precisely the same; if, instead of revolving, she were to stand still, and the orbit, supposed a solid ring or disk, to revolve or turn round on its own centre, till every point of its circumference in succession were past the moon's axis or centre. Suppose this revolution to be made from east to west, being the direction contrary to that which the moon takes in her usual progress; that the moon herself were at the same time to remain constantly at the point N (Fig. 1) during the orbit's revolution, and to keep her point *a* constantly fixed on the radius looking to the earth; the result would be that the orbit would complete its revolution without producing the smallest change in the moon's relations to the orbit itself, to the radius-vector, and to the earth at the inner end of the radius, in other words, without causing or requiring her to turn round on her axis. But precisely the same result would follow the moon's own revolution in her orbit; the same face always looking to the earth, in one with the radius, and 90° distant on either side from the line of motion; what should make rotation necessary in this case, namely, to produce results that can be shown so distinctly and undeniably to be produced without it? Again, suppose the moon to remain constantly at N, and, while the orbit revolves from east to west, to turn round on her own axis also from east to west exactly once during the orbit's progress past her. Well, when the orbit's point W reaches north, the moon's own point *a* will have turned round to *b*; when the orbit's point S reaches N, *a* will have turned round to *c*; when the orbit's point E. reaches N, *a* will have turned round to *d*; and when the orbit's point N returns to the moon on the other side, *a* will have returned to its first position in one with the radius. But, the effect of this revolution of the orbit is

that *a*, by turning round on the moon's axis, occupies at the moment at which each quarter point of the orbit reaches the moon, always the very position relatively to the orbit and the radius-vector that it would occupy, were the orbit to stand still and the moon to revolve, with her face always looking south, which astronomers say, would be the result of revolving in her orbit without turning round on her axis. Just lift the diagram, and turn it round in the proper direction, and this will be seen at once. It is, indeed, perfectly undeniable, and confutes beyond the possibility of redemption the ridiculous blunder that has so long disfigured the most perfect of the sciences.

To say, therefore, that the moon's presentation of the same point of circumference constantly to the earth, is the consequence of her rotation, implies nothing less absurd than an *orbital revolution of the earth itself*, round about the moon's axis, at the very time the moon is rotating about the relatively fixed earth! For, if the moon *rotate* with the same face constantly to the earth, the earth, to keep her in countenance, must inevitably rotate also, and in the same direction, round about the moon's axis, as if she, (the earth,) were only a part of the moon's circumference, or an outlying member attached by an inflexible radius. It might be possible for the two bodies to revolve, like the binary stars, about one common axis situate between them, and such, I believe, is the fact; but for them to revolve about each other's axis, at one and the same time, is perfectly impossible; yet nothing less than this perfect impossibility is required to support the received doctrine of the moon's rotation. But, perfectly impossible as it is, no less great men than Galileo and Laplace have both jumped at once to this conclusion, as the only discoverable means of getting out of the dilemma occasioned by the *parallelism* which we have now discussed and accounted for. The perfect impossibility of the earth's and the moon's simultaneous revolutions about each other may be demonstrated by the experimenter's taking a rod or stick, with a ball on each end, and making the two balls revolve about each other, *if he can*. One of them may be made to revolve round about the other at rest, and both may be made to revolve simultaneously about an axis between them at some intermediate part of the stick; but to make them revolve simultaneously round each other, he will soon find to be perfectly impossible. Yet, in the face of this utter impossibility, the great Laplace scruples not to say, that a person in the centre of the moon, supposed transparent, and revolving about the earth without rotating on his, or her, own axis, that is to say, preserving the parallelism we have spoken of, would *see the earth and her visual ray revolve about him*, that is,

round about the moon's axis, in the space of a month. But, true it is, that the earth, considered exclusively as the centre of the moon's orbit, supposed for the present a perfect circle, moves not a hair's breadth from her central position, and, from that immovability of the earth, it follows certainly and inevitably, that any change of relation between the earth and the parts of the moon's circumference must be the effect solely and exclusively of a movement of that circumference away from the earth round about the moon's axis.

When a globe, disk, or wheel makes a forward movement, and changes place, turning round on its axis at the same time, no part of its rotating circumference ever *falls behind* the perpendicular line that connects its axis with the road, rail, or track along which it moves. All the parts alike move forward, and it is the perpendicular radius accompanying the axis, that moves still forward, past them, *leaving them behind* in the spot they occupy for the moment, and in which they are kept back, not by virtue of a rotatory power inherent in the revolving body, but by a foreign power or force acting from without, and which only yields them gradually to the impulse of the forward-moving power, to take their turn in the forward movement. It is obvious, therefore, that if the same point of the moving body's circumference remain always in one with the perpendicular radius, (and it makes no difference whether the line of motion be a straight line or a circle, for in both cases alike the radius-vector, (in a perfect circle at least,) is invariably perpendicular to the line of motion, and always as far forward as the axis itself,) that point so remaining in one with the radius will always be on the same side of the body and its axis, and there will not, as there can not, be any rotation. The extrinsic force that retards the successive points of the circumference has no effect upon the perpendicular radius-vector; it never keeps it back, and consequently it does not keep back or retard that point of the circumference, whatever it may be, that is always in one with the radius. That point, so far from rotating backwards, is constantly moving forwards; and this is true in all circumstances; the infallible, and I may say, the only infallible sign of rotation being, that the several points of the wheel's circumference in succession pass the radius-vector, and cross the line of motion itself, 90° distant from the radius on either side. And this happens, when a body revolving in an orbit presents the same point of its circumference invariably to the same fixed point of the plane in which it moves; for in such a case that seemingly invariable point of circumference will be found to diverge from the radius on one side and return to it on the other, to *cross the orbit* of the axis twice, once in going out and once

in returning to the inside, and assuming in its progress every various degree of distance from the centre of its orbit, in proportion to the amount of progression. This ever varying change of its relation to the orbit's centre is the result of a forward movement on the part of the revolving body; but neither does the axis of the revolving body ever change its distance from the orbit's centre, nor does the centre itself of the orbit ever change its place at all; consequently, it must be the point of the revolving body's circumference that changes *its* place, seeing that its relation to the two invariable centres is constantly changing. The axis does not revolve about it, so as to get between it and the centre of the orbit; the centre of the orbit does not revolve about the axis of the planet, so as to fall behind the changing point of circumference; what remains therefore but to say, that it is the changing point itself that revolves about the axis of its own body, while that axis revolves about the immovable centre of its orbit? When, at the second quarter of an orbital revolution, the seemingly invariable point of circumference is outside of the orbit, farther distant from the orbit's centre, by a whole diameter of its own body than it was at starting, how could it possibly have got into that position, unless it had performed half an orbital revolution, or half a rotation, round the moving axis? It is no doubt true that it has not rotated under the impulse of an intrinsic rotatory power acting upon it in a circular direction. It (*i. e.* the point of circumference in question,) in common with every other point of the circumference, and generally of the planet's mass, is carried into the respective and successive positions which it and they occupy by virtue of the centrifugal force that carries the body through the circumference of its orbit; and it is the extrinsic centripetal force, acting from the centre of the orbit, that pulls continually the revolving body's axis, and makes it deflect from the straight line it would follow, and, by so pulling it, causes it continually to *leave behind* the most advanced points of its circumference, whatever these may be for the time; and the ultimate result is, that every point of circumference in succession *is left behind in its turn by the axis*, till the point which started in one with the radius-vector is again in one with it, after having performed a complete circuit round the axis, just as if, all the time, its motion forward had been retarded by friction or other obstacle acting upon it from the outside of the orbit, and pulling or keeping the circumference back, while the axis moved forward; and this circular movement of the circumference is most unquestionably *rotation*, or turning round about the axis, though it have been caused by the movement of the axis itself, that movement of the axis being in a di-

rection contrary to the natural movement of the parts of its mass under the influence of the forward-moving power.

All that I have now said may be demonstrated mechanically by the simplest means, and in the simplest manner, no more costly or more complicated apparatus being required than a common bottle-cork, with a long-tailed string tied round its middle, and a pin with which to fix it to the centre of a circle, and to serve as an axis or pivot of revolution and rotation. But I shall use an instrument of somewhat more complexity, though still within the reach of every one who wishes to try the experiment. But first let us consider the diagram fig. 2, where E and M are two circles of equal dimensions. Suppose E to remain fixed and immovable while M revolves about it from west to east. As M revolves, its several points, 2, 3, 4, 5, 6, 7, 8, 1, will present themselves successively in that order to E's corresponding points; but, in doing so, M will necessarily turn round *once* on its axis, and all the points in succession will pass the radius-vector, or straight line that connects the centres of the two circles, and of course revolves with M round E's centre point. Let M revolve a second time, with the same point of its circumference No. 1, always in contact with E's circumference, and in one with the radius-vector. It will revolve without giving the smallest token of rotation, yet say astronomers, M in this case has turned once round on its own axis, though that has been rendered impossible by its adherence to the radius-vector. In the first revolution also it turned *once*, and no more than *once*, why should the *one* invisible and imperceptible rotation which they ascribe to the moon, produce such different results from those of the visible, real, and undeniable single rotation of M, as shown in the diagram, and of every other body similarly situated, or revolving in an orbit? Let M revolve a third time, turning its points from east to west, or what is the same thing, preserving the perfect *parallelism* of all its parts to the two sides of the paper, it will present its points successively to E's points in the reverse order, 8, 7, 6, 5, 4, 3, 2, 1, to E's, 1, 2, 3, 4, 5, 6, 7, 8, and each of them in its turn will pass the radius-vector *once*. In this case it is said to revolve in its orbit, *without turning round on its axis*; yet has it shown every requisite token of rotation, and carried its several points in succession to an always increasing angular distance from the orbit's centre, till each of them has become the outermost point of its circumference, and from that extreme distance of 180° , as shown by its position below E, returned *by the other side of the axis* to its first position, just as if M. had turned round on its axis all at once, without moving forward in its orbit. How can these points get to the *outside* of the circumference, unless the body

turn round on its axis; or, what is the same thing, unless each of the points describe an orbit of rotation round M's axis, which remains invariably at the same distance from E's centre? Let this question be answered if it can consistently with the theory of lunar rotation.

The real rotation of the revolving body, in the case of so-called parallelism, may be shown by this experiment. Make the disk M of pasteboard or stiff paper, mark it as in the diagram, and fix it by a pin through its centre to the outer end of a material vinculum or radius-vector, which shall revolve by its other end round E's centre. Above the disk M, also on the pin, place a smaller disk, just large enough to show distinctly the same marked points of circumference; and then place the radius with its two disks on the line NS. In revolving, both of the disks on the pin would keep their places, with their points 1, 1, on the radius all round; but while the smaller disk, which is virtually nothing more than M's axis itself expanded, for the sake of distinct perception of the changes it might undergo, keeps steadily with 1 to the radius, make M turn round on the pin continually, precisely in proportion to the velocity of the orbital revolution of its axis, degree for degree, and minute for minute, and it will preserve its *parallelism* throughout the revolution; but that it has not the less *rotated* is unquestionable; for the experimenter's own fingers have pushed it round, carrying its successive points of circumference continually past the radius-vector, and away from E's centre, to the extent of 90° or a quarter rotation, in each quadrant of the orbit; while, on the other hand, the small disk certainly has not turned round upon its axis, the pin; the pin has not turned round in its place on the radius; and the radius has not *turned back* at E's centre, or changed in the slightest degree its proper perpendicular relations as the shortest straight line between the centres of E and M; or, in other words, it has not rotated or turned round about on M's axis, any more than E's centre itself, with which such a rotation or a change of position in respect of any point fixed or moveable on the circumference, is impossible. What remains then but to admit the fact, that the so-called parallelism is produced by M's retro-rotation from east to west, while its axis revolves from west to east, with all the parts and molecules of the mass moving along with the same degree of velocity under the influence of the centrifugal power acting upon them through the axis? On the other hand, were both the disks alike to keep the same points 1, 1, on the radius, it follows certainly from the same premises that neither of them rotates on the pin axis, but that the mass of each simply revolves from west to east with different degrees of velocity proportional to the diametric or radial distances of its particles from

the centre of E, just as if they were integrant particles of E's own mass, turning round about their (E's) own axis. The radius-vector is, in all cases and circumstances without exception, virtually an integrant or integral part of the orbit and its centre, and can no more change its relation to that centre by revolving or rotating about the axis of a planet or satellite than the orbit's centre itself can. Such a revolution or rotation of the orbit's centre is absolutely impossible; and for the radius-vector it is equally so. The axis, moreover, of a planet or satellite, is, like the radius-vector, only an imaginary line incapable of any movement independent of the mass of which it forms a part. Therefore, it cannot be said in any case that the axis itself rotates while the body does not. In the case, however, of a common wheel, with a separate axle, that might be said; but I have shown already that it would be said without ground.

This same diagram will serve very well to show the nature and the cause of that *parallelism* which has been mistaken for the effect and sign of non-rotation. Each of the disks has a diameter of one inch, and a circumference of three inches, or thereabouts; consequently the orbit described round E's centre by the innermost point of M's diametric breadth a , measures *three* inches also; while the orbits described by M's central axis and the outermost point of her diametric breadth b , measure respectively *six* inches and *nine*. These several orbits are described by the revolving body equally in all the three cases of revolution just spoken of, showing most plainly that, whether the revolving body turn round on its axis or not, it is not in the least degree affected in respect of rotation or non-rotation, by the great difference of dimensions that exists between the orbits of its outermost and innermost points of circumference, whether these be always the same points, or a series of points changing continually. It might appear, indeed, that if the outermost point travel so much faster than the innermost point, it would push the latter round the axis; but this is prevented by the axis itself moving forward always in line with the two points a and b , and the effect of that forward movement of the axis is that it (the axis) and b virtually revolve about a , instead of a 's partaking with b in a rotation round the axis. Strictly speaking, they, along with a , revolve in one line round about the centre of the orbit, just as if they were all three points in the lineal extension of the radius-vector. This is really the case when the body revolves without rotating; but, when it does rotate, the points of circumference change places continually, while the radius-vector alone, or the points in its length, describe the two orbits corresponding to the outermost and innermost points of circumference, the axis itself remaining always on the radius, in line between them. If the three points a , b , and c (axis) were to move along with equal degrees of velocity, it is

perfectly true that at the end of the first quadrant of c 's, or the middle orbit, a and b would be perpendicularly in line with it, or parallel to the meridian NS; and a rotation backwards (from west to east) would bring a back again to the radius. But, in fact, the moon does not move in this manner; the same point of her circumference remains constantly in one with the radius, always on its own orbit, at the same distance from the centre; and as the three points of her mass really do revolve under this condition, the result is that, when a finishes its quadrant, c and b would be 90° behind it, unless a rotation or forward movement to that extent *bring* them into their proper places upon the radius, in line with a . This is effected gradually by their moving faster than a , in proportion to the greater dimensions of their respective orbits, so that they remain in line with a upon the radius, all the way round, without disturbing a 's or their own relations to the radius and the centre; or, in other words, without the body's rotating on its axis. The cause of the moon's not rotating backwards, from east to west, or preserving her *parallelism*, as she naturally would, were she to revolve with her circumference *free*, and her axis alone subjected to the centripetal force, we shall consider by and by.

Take a stick or rod of any kind, and attach it by one end to a fixed point on a floor or a table, and then to one side of its outer end attach a disk of any size or substance by a nail or pin stuck through its centre. Make the rod revolve from west to east round the point to which it is attached, and at the same time keep the disk continually turning round on its axis. Turn it round and round, backwards or forwards, its relations to the radius and the centre will remain unaffected by the revolution of its axis in its orbit, though the relation of that axis to every object outside of the orbit will be continually changing; and this happens because the revolution of the axis carries forward the whole mass simultaneously with, and in the line of, the radius-vector, without changing its relations to the points of its own circumference. If the same point remain always in one with the radius, it will, of course, never change its relation to the axis. If the whole circumference pass the radius once in an orbital revolution, it will change its relations to the axis once also, and *only once*; but, if that change and passing of the radius once be made in the direction from east to west, the parts of the mass will preserve their so-called parallelism, by virtue of the forward motion of the axis in the contrary direction, which affects the relation of the circumference to extra-orbital objects, but not at all to the axis itself, or to the radius-vector and the centre. The same thing will appear still more clearly, if possible, by a variation of this experiment, Make a large disk, and fix it to a table or floor by a pin through its centre, to serve as an axis of revolution. Near

the outer edge of its circumference attach a small disk by a thread through its centre, to serve as its axis. Draw a straight line between the two axes to represent the radius-vector, and then make the large disk revolve on its axis, and it will be seen at once that, in whatever direction it may be turned, the small disk will remain as unaffected by the movement as if it were an integral part of the mass, and that the relations of the several points of its circumference to the axis and the radius are affected by its own movements *only*, round its own axis, quite independently of the movements of the large disk to which it is attached. The lid of a small pill-box will answer nicely for the small disk, if a thread be attached to one point of its circumference, having its other end fixed to the centre of the larger disk, and the large disk be made to revolve with the *parallelism* of the small disk preserved, the thread will be drawn all round the small disk, showing incontestably that disk's rotation on its axis.

Upon the face of a wall, or other flat perpendicular surface, draw a circle one foot in diameter, and divide it into quadrants by two diametric lines crossing at right angles in the centre. Then take a stick, staff, or rod, one foot long, with four square sides, and attach it by a hinge or other ligature to a fixed pivot in the centre of the orbit. At the middle of the rod, which of course will be the distance of the orbit from its centre, fix another pivot, (on the rod itself, not on the wall,) and on that pivot hang a string with an open loop, having at its other end a plummet which shall keep it stretched as far as the centre of the circle, when the rod is placed perpendicularly with its whole length above that centre. In other words, the string, including both loop and plummet, must be of precisely the length of half the rod, or six inches. Mark the quadrants as N, W, S, E; N and S being at the opposite ends, N at the upper, and S at the lower end of the circle's perpendicular diameter, while E. will be at the right hand end, and W at the left hand end of the cross diameter. Then attach the rod to the centre of the circle on the line N S with its own middle or pivot *c* on the orbit at N; and on the latter pivot hang the looped string and plummet. The lower half of the rod, while so attached to the centre of the circle, will, of course, be identical, or virtually the same, with the mathematical radius-vector of the pivot *c* to which the plummet is hung. When thus prepared, set the machine in motion, making the rod revolve round the central pivot of the circle, from west to east, that is to say, from right to left at starting, so continuing always forward in the same direction. As the rod revolves, the plummet will be seen diverging from it to the left, in the same proportion, degree for degree, moving away from the centre of the circle, just as its own pivot *c* moves

away from N ; but keeping the stretched string always parallel to the perpendicular diameter NS, and to the two cross walls to the right and left of the room where the experiment is made ; and when the rod completes its first quadrant and reaches W, the plummet will have also described a quadrant for itself of the same dimensions, will have crossed the orbit to the outside, and will have reached a point at the angular distance of 90° further from the centre of the orbit than the place it occupied in contact with the centre just before starting, and at right angles with the rod and its axis, showing, in my judgment, a rotation of 90° round that axis. In the second quadrant, the plummet will again describe a quadrant for itself, and will reach a point still further distant from the primary centre by another 90° , or, altogether, 180° , directly outside of its pivot. But, how could it get there, unless it had performed a rotary movement of 180° round that pivot ? It has, unquestionably, by its regular movement under the law of gravity, described a semicircle of that angular extent, and of the same real dimensions as the orbit of its revolving axis ; and the change of their relations to the primary centre cannot be ascribed to the revolving axis, for that axis has kept at precisely the same distance from the primary centre, and with its radius-vector always subtending the same rectangle with the orbit, during the whole passage of 180° ; and, as it is the plummet's real and visible movement that has brought it into that situation, that movement must be resolved into its elements, as partly progressive along with its pivot, and partly rotary about that pivot, the effect being precisely the same, as if the string and the plummet had lain upon the rod during its passage of the quadrants, and then been set at liberty, when it would have run through the angular distance of 180° at one sweep, and something more, only settling at the 180^{th} point, after oscillating till tired. Through the next two quadrants, this process will be repeated, in the reverse order, and when the rod returns to its first position, the plummet will again be in one with the centre of the orbit. The diagram, (Fig. 3,) shows the relation of the orbits described by the two moving bodies, the continuous circle being the orbit described by the pivot or middle point of the rod, and the dotted circle being the orbit described by the plummet. To prove further the reality of the plummet's revolution round the pivot *c*, take a flat cylindrical disk, thick enough to carry a cord on its edge, fix it by its centre on the revolving pivot of the rod, mark its quadrants, N, S, W, E, and to the point S, in one with the line NS of the primary circle, attach the plummet by its string. Then make the rod revolve, as before, from west to east ; the plummet will be seen again describing an orbit of its own, partly within and partly without the

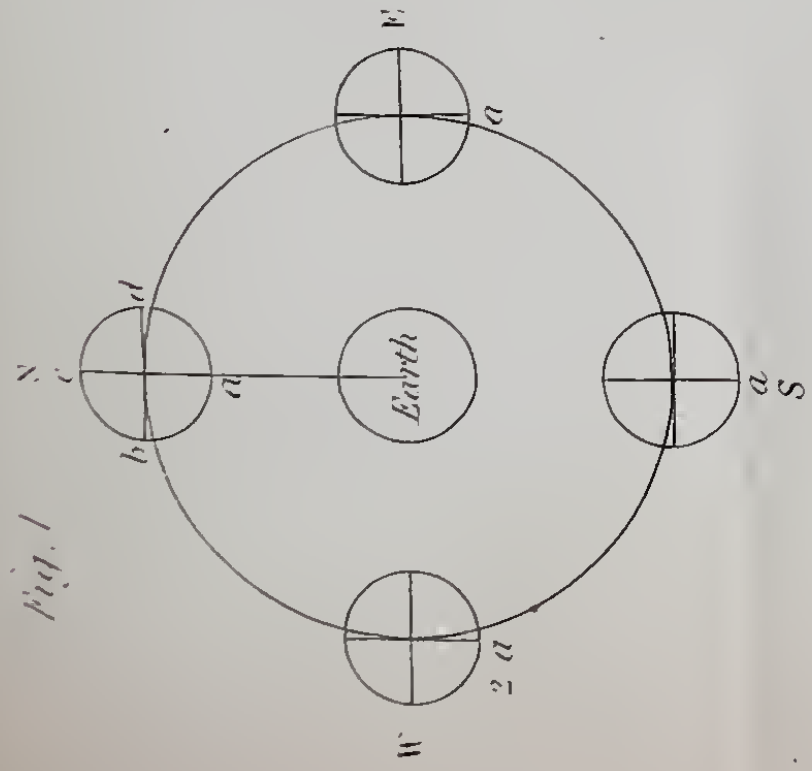


Fig. 1

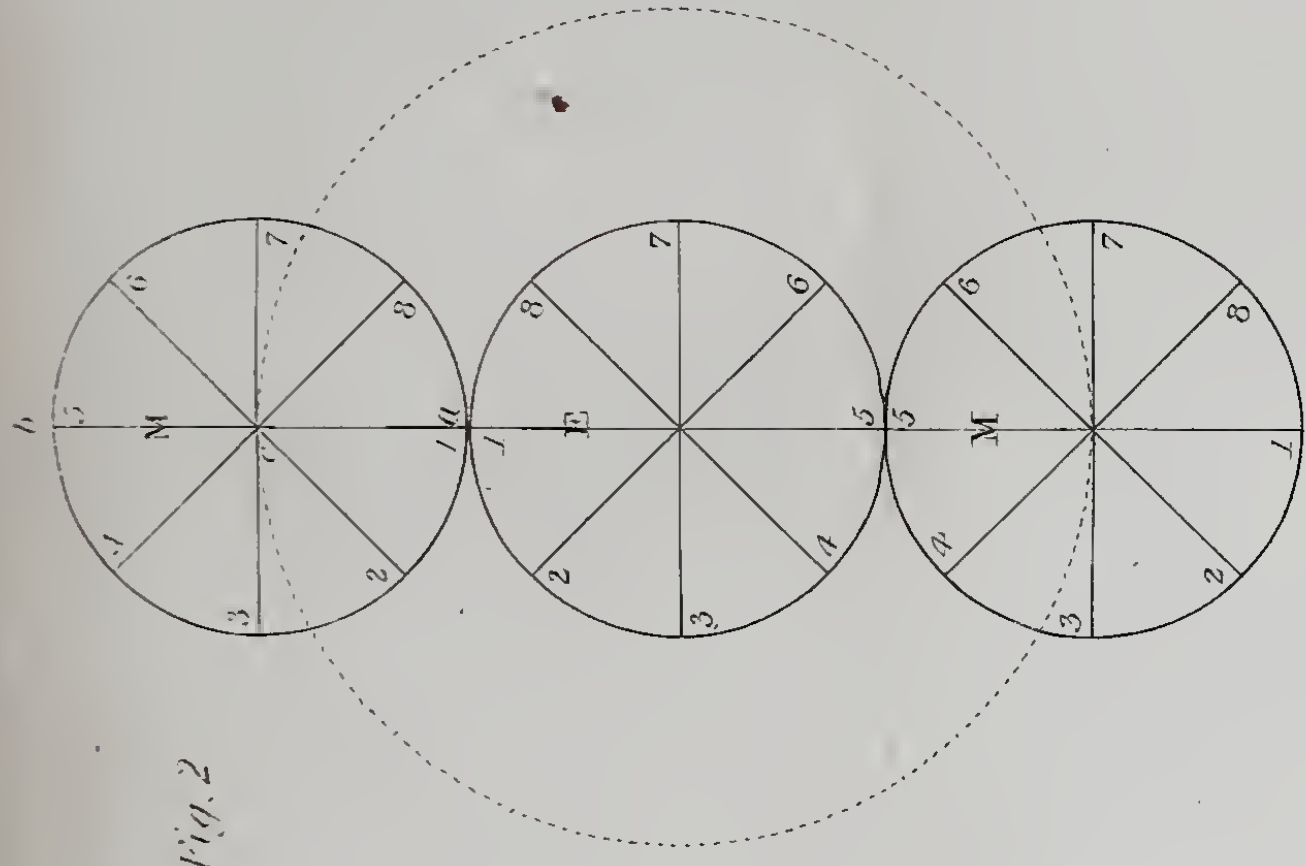


Fig. 2

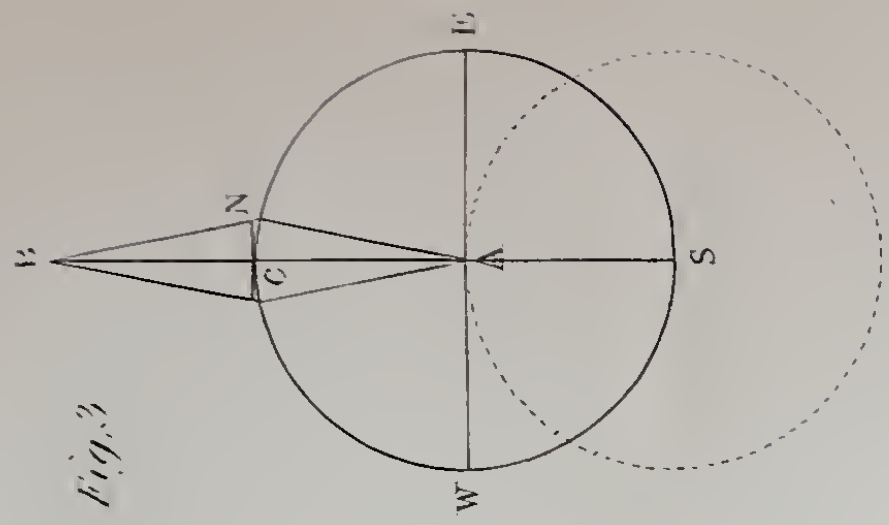


Fig. 3

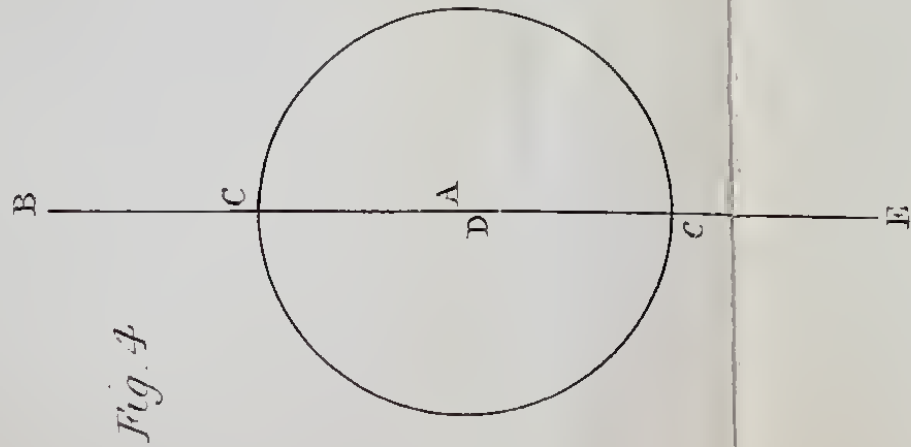


Fig. 4

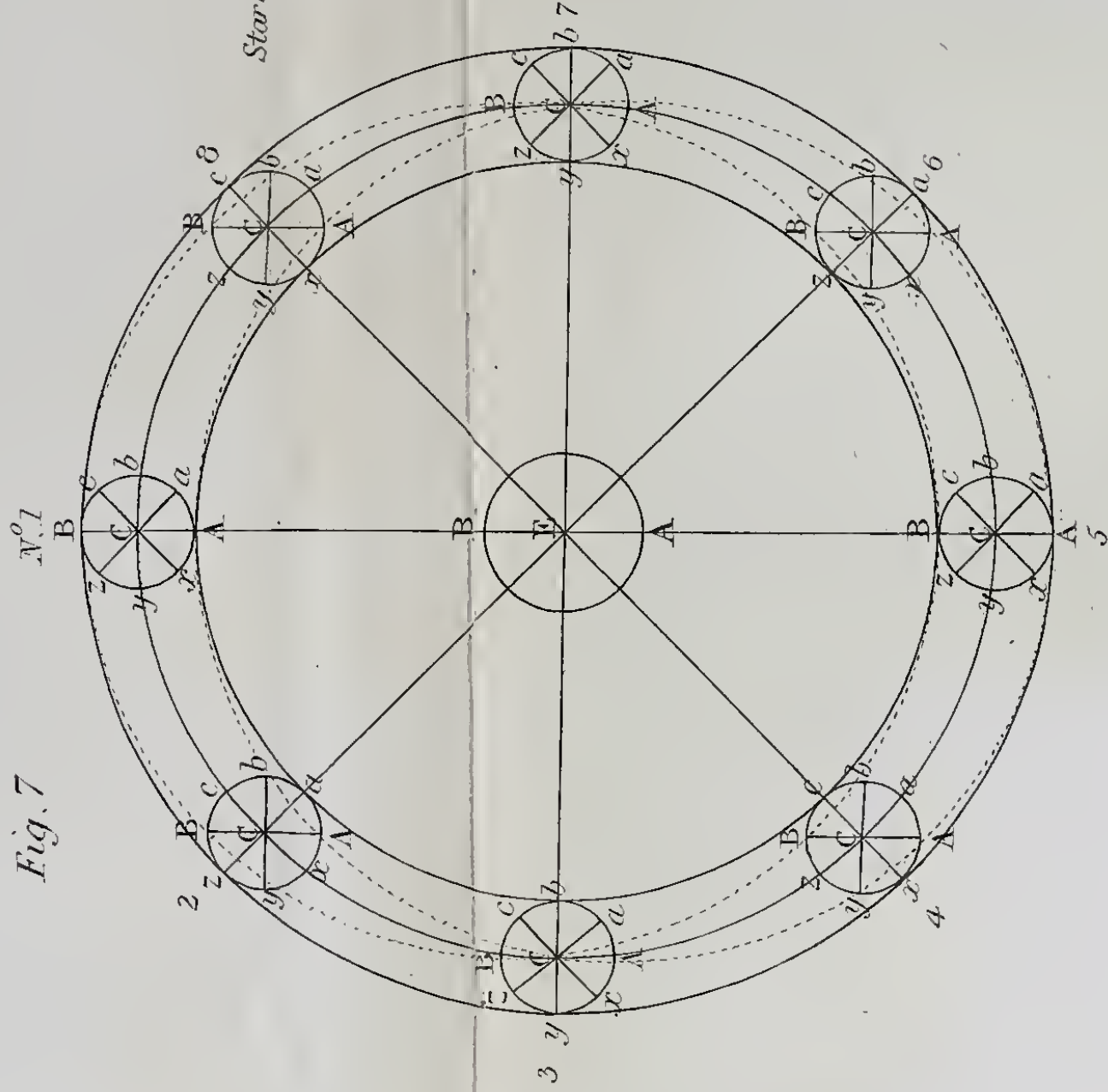


Fig. 7

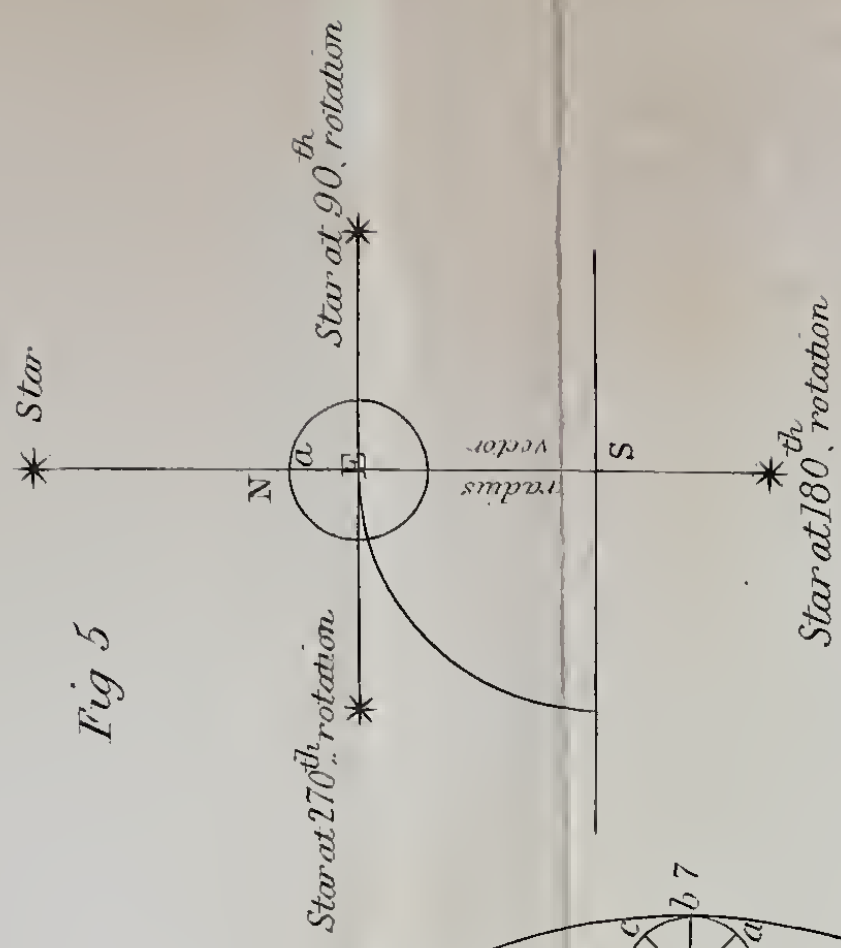


Fig. 5

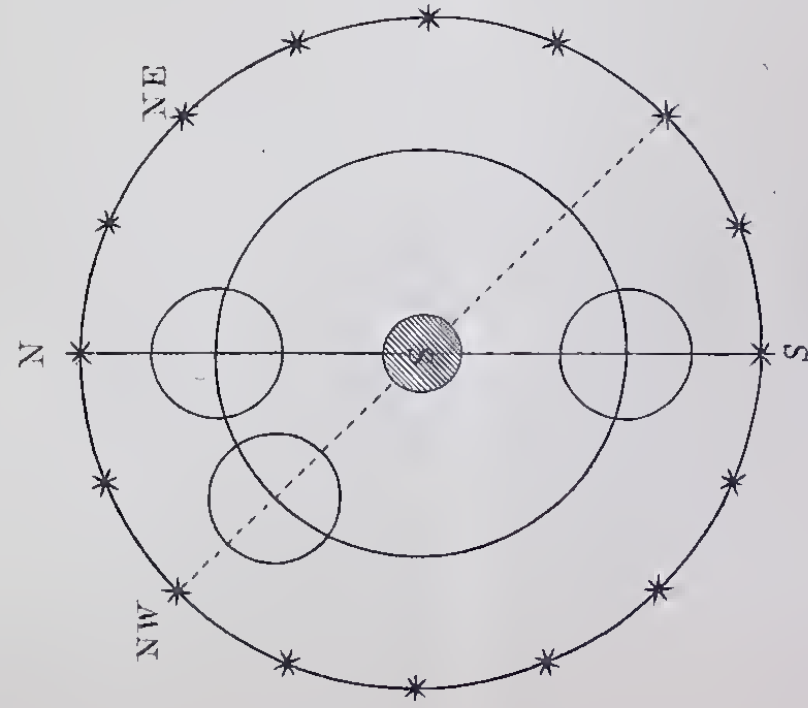


Fig. 6

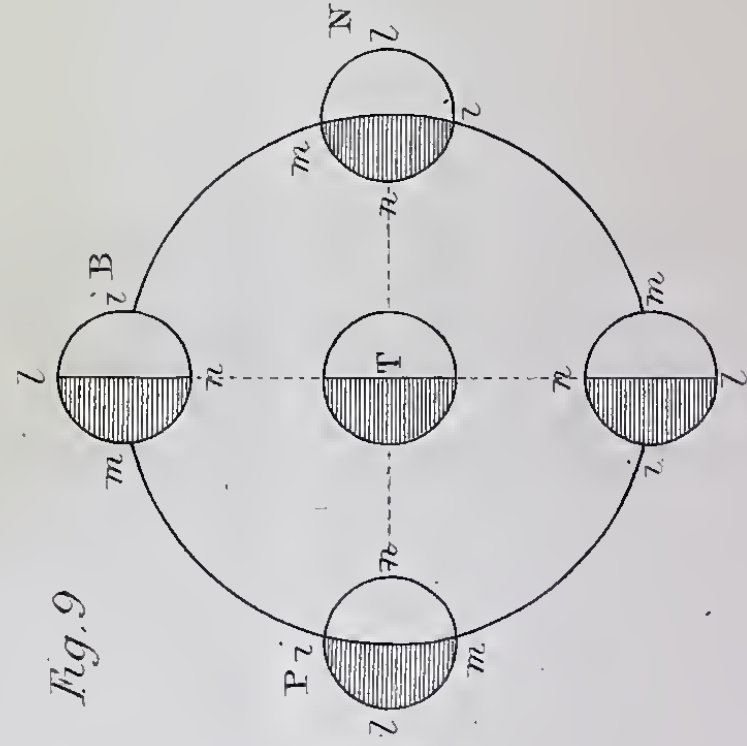


Fig. 9

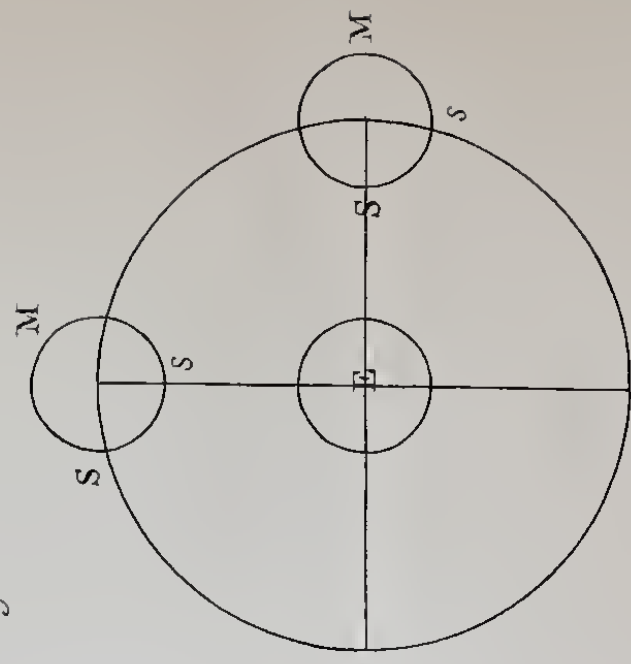


Fig. 8

primary orbit; but, the disk being fixed to the rod, and not turning on the pivot, the plummet's cord will gradually wind itself round the disk's edge, and when the rod has completed its revolution, the plummet will again be in one with the diametric line NS, but its cord will be round the whole circumference of the disk, a thing which could not possibly happen unless the plummet's rotatory revolution carried it round that edge.

At each quarter point of the circle on the wall, draw a strong and distinctly marked cross, and mark the points of each that are nearest the centre, *a, a, a, a*. It is obvious, from the nature of the case, that they cannot turn round on their axes; but if it so happen that the rod AB moves successively past them all in the course of the orbital revolution of its own axis, while its true or mathematical radius-vector preserves invariably the same relation to each of the four crosses, and to each of the four straight lines that connect these crosses with the centre, is it not equally obvious that that radius-vector moves forward along the orbit continually, and altogether in the same direction with all its points, without turning round on the axis of the revolving rod any more than the fixed crosses themselves turn round on their axes? They have not rotated on their axes; how comes it then that the radius-vector, rotating as alleged round the moving axis, is always in one with the same unmoved arm of each of them? Again, across the rod AB, at its pivot or axis, place a cross bar of say three inches length, and attach the ends of this cross bar to the two ends of the rod by wires or tight strings, forming altogether two triangles, on the opposite sides of a common base, and having the vertices respectively at the opposite ends of the rod, as in Fig. 3. It is obvious from mere inspection of the diagram that if the two ends of the base change their relation to the orbit, by the one going outwards and the other going inwards, that change implies, and can only be the result of, *a rotation on the axis*. But, if the two ends of the base rotate, the rod, from whose points they are 90° distant on either side, must rotate also, whether that rotation be from west to east, or from east to west. In both cases alike it must diverge from the radius-vector, which can never forsake the centre, or change its relation of perpendicularity to the orbit; but, in diverging and rotating from east to west, *contrary* to the direction of the orbital revolution of its axis, the rod will necessarily preserve its much vaunted *parallelism*, that parallelism which deceived Galileo, and has deluded all his followers for two centuries. On the other hand, if the diverging of the cross-stick from the line of motion necessarily implies rotation, the remaining of that cross-stick on the line of motion equally implies *non-rotation*; and, when it does remain so, the rod AB itself will remain always in one with the radius-

vector, which never does, and never can, turn round about the revolving axis.

The plummet being removed, and a long loose cord attached to the same point of the cylindrical disk, and having its other end fixed to the primary centre of the circle, make the rod revolve, and it will complete its revolution without affecting the cord, without drawing it round the cylinder, showing unequivocally that there has been *no* rotation there. Now, detach the rod from the primary centre, and make it revolve, preserving its parallelism with the line NS, so that its inner point A will now describe exactly the same orbit for itself as that described by the plummet. When it completes its revolution in this parallel fashion, strange to say, though it has revolved, as astronomers allege and profess to believe, without turning round on its own axis, it will nevertheless have drawn the cord round about the fixed cylinder which has been revolving with it, also without rotating on its axis, as alleged. But how can the cord get round the cylinder if the cylinder has not rotated on its own axis? And if the diameter of the cylinder were to be made as large as the rod itself, then the cord would be drawn round both the points of the revolving rod, notwithstanding its pretended avoidance of rotation by preserving its parallelism. And that the movement which has occasioned the drawing of the cord round the cylinder has been exclusively on the part of the rod itself, will be evident from the fact that the cord's movement begins at the end attached to the moving rod, and is affected through its whole length, and at its central end only, when the cylinder's rotation has drawn it all away from the centre; and, moreover, by the fact that when the rod was not loose, and consequently did not move away from the centre, the cord remained entirely unaffected by the pivot's revolution, showing that there was no motion in the opposite direction, on the part of the primary centre and the radius-vector; and if there was no such opposite motion in that case, there could be just as little when the rod was loosed, and it and the cylinder left at liberty to turn away from the centre.

To meet such arguments and illustrations as these, astronomers and mechanicians have nothing better to offer than the following notable proposition. "Let AB (Fig. 4) represent an inflexible rod of no weight supported by a hinge at the point A, in the centre of a circle, in such a manner that it may turn or revolve freely round that centre. When it so revolves, its motion may be divided into two; one progressive, by which its centre of gravity C changes its relative position to other bodies, and the other rotatory round that centre, *by which its parts change their positions with regard to one another.* If it make a complete revo-

lution round the circle by its point A (attached to the centre by a hinge) its parts in the same time will make a revolution round the centre of gravity C." The first and most obvious remark upon this notable proposition is, that the latter part of it, all that is in italics, is wholly untrue, and most directly contrary to the truth; and I cannot comprehend how any man in his right mind should ever have been able to persuade himself that it is true, unless, indeed, it were on Tertullian's principle of believing a thing *because it is impossible!* When a rod so situated revolves round the centre of a circle, not only "its centre of gravity C," *but also all the other particles of its mass*, "change their positions relatively to other bodies;" while, on the contrary, were it to rotate on its axis C, whether that rotation be visible or invisible, "its parts would *not* change their positions with regard to one another." They would, on the contrary, preserve invariably the same relations to each other, to the orbit's centre, and to their own axis or centre of gravity, but would change their relations continually to everything else. This seems to me perfectly self-evident. It must follow, at least, from what I have shown already; and the only *reason* astronomers can give for maintaining such a proposition is, that, if it were not true, their doctrine of the moon's rotation would not be true either. The doctrine and the proposition are thus perfectly consistent with each other, but their truth is just as problematical, and, not to mince the matter, just as *false* as the ancient doctrine which placed the earth in the centre of the universe, and made the sun, moon, and stars, the whole host of heaven, revolve about it. The proposition above quoted has not even such *appearance* of truth; for it is just as directly contrary to *appearance* as to *fact*; and no man in his senses would ever have believed it, had he not first persuaded himself, on other grounds, that it must be true, in spite of appearances. In short, the proposition is not an induction from observed facts, but only a deduction from an erroneous hypothesis, contradicted by facts.

The latter part of the proposition, "if the rod makes a complete revolution round the circle by its point A (*attached to the centre by a hinge*), its parts in the same time will make a revolution round the centre of gravity C," is just as utterly untrue and contrary to fact as all the rest. Take two rods of equal length, each attached by a hinge to the centre of the same circle, but on opposite sides, so as to form together one diameter of the circle, or, what would do as well or better, take a single rod of double the length of the rod AB, and fixed by its middle upon a pivot in the centre of a circle or orbit, whose circumference shall be described by the middle part of each half of the rod. Call these two centres of gravity C and *c*, and the two halves AB, with its axis C, and DE with the axis *c*. These are virtually two distinct rods,

and as such are radii of the circle to whose centre they are attached, and whatever is true respecting one of them must be equally true respecting the other. If, therefore, the rod AB rotate on its axis C during the orbital revolution, the rod DE must, by parity of reasoning, rotate on its own axis c . At the same time both rods together rotate, as radii of the circle, round the centre of the circle; so that each of them, during a complete orbital revolution of their respective axes, performs three distinct revolutions round about no less than three distinct centres *all at once*: AB turns round, 1st, the common centre; 2^d, its own axis C; and, 3^d, DE's axis c ; while DE also turns round, 1st, the common centre; 2^d, its own axis c ; and, 3^d, AB's axis C. The same thing must happen with every pair of opposite spokes in every wheel: each spoke is the radius of a circle, attached to the centre like AB; and if AB rotate on its own centre of gravity at the circumference of the circle, so must each spoke, placed as it is in precisely the same circumstances, revolve round its own centre of gravity, and, with the help of its opposite neighbour, perform *three* circular revolutions, round three different axes, where no human eye can see, and no human understanding can discover the possibility of more than one, namely, that round the axle of the wheel, the common centre of all the radii. Again, if AB turn round on its own centre C, each half of AB divided by C will also, in each rotation of the rod round C, turn round on its own centre of gravity, and so on, as far as matter is divisible; so that in every case of a body's revolving on an axis, we should have an infinite multitude of wheels within wheels, all revolving and rotating at once; but which will be all swept away at once, like the Ptolemaic cycles and epicycles, by means of the simple truth, that in the case of the rod AB and of all bodies similarly situate, as the diameters and radii of wheels, moons, and planets, there is and can be only *one* revolution round *one* centre, namely the centre of the orbit, *so long as the same point of the rod, the same end of the diameter, or the same point of circumference of the revolving body remains in one with its radius-vector and the centre of the circle.*

But, say mechanicians and astronomers, if the rod AB were not to rotate on its axis, its point A would move away from the centre, and all its parts, in length, would remain perfectly parallel to the straight line NS of our first experiment on the wall. To be sure it would, but the nature, the cause, and the result of such a movement and such a parallelism have been abundantly shown already. Such a movement of the point A from the centre would be an act of rotation round its own axis C. Moreover, such a rod as AB has no inherent power of rotation to *bring* its points *back* to the radius-vector; therefore

the “hinge” of the proposition is used as a substitute, and the effect of that hinge is to hold A fast, and *keep him from rotating* round about C, as he naturally would were he *free* to obey the impulse of the centrifugal moving power. It is indeed an absurdity to talk of *bringing back* what never goes away. The correct expression in the moon’s case would be, that her inherent power of turning round on her axis, if she really possess such a power, in a direction contrary to that of the impulse given to her parts by the centrifugal power, *neutralizes* that influence so far as to *keep* the same point of her circumference continually in one with the radius-vector, and so to make her revolve in her orbit continually, *without turning round on her axis*, to a greater extent than that indicated by her libration in longitude, which is a real oscillation on her axis, occasioned by the ellipticity of her orbit, and her varying velocity in the different parts of that orbit.

The same thing may be proved by an experiment on a great scale, performing continually between earth and heaven. The earth’s centre is not the centre of the moon’s orbit; but the two bodies together have a common centre of gravity situate at a certain distance between their axes, and round that centre of gravity both axes revolve. The distance between the earth’s proper centre or axis and that centre of gravity is the measure of the radius-vector which connects the earth’s axis with that centre of revolution, and is just a prolongation of the moon’s radius-vector, as if the two radii-vectores together, however different in length, formed but one inflexible rod revolving on a pivot at the centre of the system. But, if it be true that the moon’s radius-vector revolves about the moon’s axis, and revolve about that axis it must, of the point of the moon’s circumference that is always in one with it, so revolve, as alleged, then the earth’s radius-vector must also revolve round the earth’s axis; and both radii forming virtually *one* inflexible rod, must, like the double rod, AB, DE, simultaneously perform three distinct revolutions; 1, round the common centre of gravity; 2, round the earth’s axis; 3, round the moon’s axis; *all at once*, which is perfectly impossible.

The preceding argument and illustrations respecting the rod AB apply precisely to the case of a globe revolving in close contact with the centre of its orbit; the diameter of such a globe being represented by the rod AB; and whatever is true or false respecting the rotation and revolution of that rod, is equally true or false respecting the revolution of the globe whose diameter it represents. The effects and changes produced by the revolution and rotation in immediate contact with the centre of its orbit are not in any respect different in kind from the effects

and changes that are or would be produced by the revolution and rotation of a globe at the far end of a radius-vector, of any conceivable length, even to the orbits of Herschel and Leverrier, or beyond them; for the radius-vector is the instrument and accompaniment of the revolution, virtually a part of the orbit itself, representing the corresponding point of the centre's own circumference, at the point of the orbit where the globe may happen to be for the time, and the index of the globe's rotation, or turning round on its own axis, every point of the globe's circumference inevitably passing the radius-vector once in every complete rotation. Metaphysically considered, indeed, the centre of an orbit is an imaginary point, without length, breadth, and thickness; but considered physically, it is a certain portion of space, with a certain definite circumference, however small, divisible into any number of parts or degrees like the orbit itself; so that the orbit is virtually the centre itself expanded to those limits, as, on the other hand, the centre is virtually the orbit itself contracted to the smallest conceivable limits; consequently, whatever could be truly predicated concerning any point of the orbit, or concerning a body moving along the orbit, could be just as truly predicated concerning the same or a similar event at any point of the centre itself.

The principle, and the fact of retro-rotation, may be beautifully and perfectly illustrated by the movements of a magnetic needle in a compass-box. Fix the box, containing the needle, to the outer end of a rod or radius-vector that shall describe a circle round its other end fixed in the centre, in such a way that the two ends of the needle shall be pointing directly to the north and south points of the card fixed immovably in the bottom of the box. Then make the radius revolve from west to east, carrying of course the box along with it. As it revolves, the card will be seen to carry its point N, in the same direction away to the left of the needle's north point, and so on round the whole circumference, every one of its points in succession passing the needle, which will seem to stand still, and remain invariably pointing in the same direction, or maintaining an invariable *parallelism*, as if it were facing the sun or other stationary spectator outside of the orbit. Now, in this case, one of three things happens,—1st, the box *fixed*, though it be to the radius, turns round on its own axis; or, 2^d, the radius itself, carrying the box along with it, turns round on its own centre of gravity or the pivot in the box; or, 3^d, the needle, which is *movable* on its pivot, turns round on that pivot, while the box and the radius revolve without rotating. To prove which of them it is that rotates, just *fix* the needle in line with the radius, in the direction NS, so that it shall not move on its pivot; then make the rod revolve, and box and needle alike will

remain in the same invariable relation to the radius-vector and the centre of the orbit. But, at the first quarter, or at any other intermediate point short of the half-circumference, set the needle at liberty and it will fly back to its natural position, directly north and south, while the box and the radius will remain as before, in the same undisturbed relation to the orbit's centre. The cause of the needle's rotation is well known, and sufficient to account for the phenomenon; while there is no apparent or probable cause of rotation in either the box or the radius. It is, therefore, the needle that rotates, and neither the box nor the radius; yet the effect of that rotation is to keep the needle in the same direction of *parallelism*, the very result which, in the moon's case, astronomers would ascribe to her *non-rotation*.

A ship sailing round the world is placed in circumstances precisely similar to those of the moon. It describes a circular pathway on the earth's surface, with just as much freedom of movement as the moon herself possesses in her orbit. If it were to move under the influence of the centrifugal or tangential force alone, represented in its case by the wind or steam that drives it along, it would move straight forward, and continually lift every point of its circumference in succession from the water, just as the moon, if equally free, as astronomers assume that she is, would turn her points successively away from the earth. But the moon, it is said, possesses a power of rotating on her axis in a contrary direction, and that power "*brings*" the outward turning point continually "*back*" to the radius. It is not easy, indeed, to conceive what can be meant by "*bringing back*" what not only never goes away, but on the contrary *keeps* invariably the same position. To speak, therefore, more correctly, we should say that the alleged power, if it exist, *keeps* the same point of the moon's circumference continually in one with the radius-vector, and prevents its ever moving away at all, so as to require "*bringing back*." It just neutralizes the natural tendency to turn her circumference outwards, which the moon would have if she were free. But the ship, it will be admitted, does not possess such a power to bring its prow continually back to the water, and so to keep its keel continually directed to the centre of the earth. By what means then does it exhibit, in precisely similar circumstances, the same phenomenon as the moon, if it want what is considered indispensable to the production of that phenomenon in the lunar globe, that ship sailing in the sky? Why does not the ship present its topmast and keel alternately, and indeed every point of its perpendicular circumference in succession, to the earth's centre, which is the centre of the orbit in which it revolves? It must either do this or bring the same point continually back to its radius-vector by virtue of some power in-

trinsic or extrinsic, like that ascribed to the moon. But the only power known or ever supposed to act upon the ship in these circumstances, is the attraction of gravitation; and if that power be sufficient to keep all the ship's particles in the same relative places with respect to the earth's centre, why should it not be sufficient to account for the moon, in such precisely similar circumstances, exhibiting the same phenomenon, that of presenting the same face continually to the centre of her orbit? In assuming the existence of such a rotatory power as that ascribed to the moon, astronomers seem to be not only guilty of the common fallacy of *non causa pro causa*; but even to fly directly in the face of Newton's laws of philosophizing, which tell them that they ought never to assume more causes of natural events than are *true*, and sufficient to account for the phenomena; and that, of natural effects of the same kind, as in the case of the ship and the moon, the causes are the same. Would not that man be thought mad who should seriously affirm that the earth's centre, along with the radius-vector, revolves about the centre of gravity of every ship that sails round the world, nay of every ship, animal, locomotive engine, and cloud, that describes an arc on, or near to, her surface? Yet, this is just what astronomers do say when they affirm that the earth with the moon's radius-vector revolves about the moon's centre during each of her orbital revolutions. Think of the earth's centre performing a gyration, or thousands of millions of simultaneous gyrations or oscillations, round about all, and each individually, of the bodies that change place on her surface, *without ever forsaking its own proper place*—the centre! Yet, say astronomers, the earth herself revolves about the moon, without ever leaving the centre of the orbit! I think, after this, I may say with confidence that the earth and the radius revolve about the moon just as much as the earth's centre revolves about the round-the-world-sailing ship, and no more, that is to say, not at all; and that the moon, like the ship, revolves in her elliptic pathway, without turning round on her axis, any more than the ship turns round on its centre of gravity.

It is to the action of the centripetal force, or of the earth's attraction of gravitation, that I ascribe the fact of the moon's non-rotation. Under the influence of the centrifugal force alone, acting upon its whole mass, while the *central axis exclusively* was affected by the centripetal force, the moon would preserve the *parallelism* already so often mentioned; and astronomers seem all to assume that the moon's circumference, and the particles or molecules of her mass between that and her axis, are entirely free from, and unaffected by, the centripetal force of the earth's attraction; and it being thus *free*, an inherent or intrinsic power

of self-rotation is required to *bring* the same point of the circumference continually *back to the radius-vector*. But if the doctrine of gravitation be true, then the earth's attraction acts, not merely upon the moon's axis to the effect of keeping her in her orbit, but also upon every point of her circumference, and every molecule of her mass, with a force proportional to the radial distance of those particles from the earth. The earth's attraction is consequently strongest upon the nearest parts of the moon's circumference, and its effect is to neutralize the forward moving impulse of the centrifugal power on those particles, and hold them fast, while the axis and the outward parts move forward in obedience to the centrifugal impetus. The general result is that the parts of the moon's mass revolve in their respective concentric orbits with different degrees of velocity proportional to the dimensions of those orbits, without rotating on her axis, which actually describes a larger orbit, or moves faster forward than the inner point that is said to rotate round it. Astronomers are indeed perfectly aware of this real influence of the earth's attraction, though they have all agreed to overlook it; for they say, to use the words of Mrs Sommerville, varied a little from Laplace, "the lunar spheroid has three principal axes of different lengths at right angles to each other. The one directed towards the earth is the greatest. The *attraction of the earth*, as if it had drawn out that part of the moon's equator, *constantly BRINGS the greatest axis*, and consequently the same hemisphere, *towards us*." If, instead of *brings*, they were to say *keeps*, this quotation would, in my opinion, express the true state of the case; for, certainly the point remaining in one with the radius-vector never falls back a hair's breadth; it moves constantly and continually forward with the radius-vector, in line with the axis itself, and never changes its relation either to the axis of the moon, or to anything else within the orbit of that axis, except to a small extent occasioned by the eccentricity of the orbit, the earth's position in one of the foci, and the varying velocity of her progressive movement. To that extent the moon vibrates or oscillates on her axis, but she certainly never completes a rotation.

This oscillation or vibration, very properly called the moon's *libration* in longitude, is said by astronomers to be the effect or result of the *uniformity of her rotation*, and the *irregularity* of her orbital movements; for "the motion of revolution is sometimes slower, sometimes more rapid. The apparent vibration, therefore, which it occasions cannot always exactly counterbalance the actual rotation, which remains constantly the same; and these two effects will surpass each other by turns." But, the moon's so-called "uniform rotation" being no rotation at all, some other cause must be sought for the libration than the one assigned; and it seems to be this.

“The Moon,” says Sir Isaac Newton, “is revolved about its axis by a motion *most equable* in respect of the fixed stars, viz., in 27 days, 7 hours, 43 minutes, that is in the space of a sidereal month; so that this diurnal motion is equal to the mean motion of the moon in its orbit: upon which account the same face of the moon always respects the centre about which this mean motion is performed, that is, the exterior focus of the moon’s orbit nearly; and hence arises a deflection of the moon’s face from the earth, sometimes towards the east, and other times towards the west, according to the position of the focus which it respects: and this deflection is equal to the equation of the moon’s orbit, or to the difference betwixt its mean and true motions, and this is the moon’s libration in longitude.” The moon, at apogee, directly faces the earth; but, when she leaves that point to move along the west side of her orbit, if she were to move under the influence of the centrifugal force alone, that force would make her inner points of circumference turn gradually outwards, in the direction from east to west preserving their parallelism; but, as she proceeds, the elliptic orbit becomes gradually flatter, and that increasing flatness proportionally diminishes her tendency to retro-rotate, or parallelize, in as much as the direction of the centrifugal impetus gradually approaches the line of the orbit described by her axis, and consequently carries forward all the particles of her mass in lines always becoming more nearly concentric to or parallel with that orbit. At the same time she is getting continually nearer the earth, and that approach directly increases the earth’s power of attraction on the nearest parts of her circumference, enabling it to hold them faster. She is also continually increasing her orbital velocity, and the immediate effect of that increase is to leave the attracted portions of her body more rapidly behind, while the less attracted axis and outward parts roll forward. None of the parts ever move backward; for, if they did, that would imply two motions in the same body, in contrary directions, at the same time, which is impossible. They are simply left behind in the forward positions which they had previously gained. By the combined operation of these causes the result mentioned by Sir Isaac, that the moon’s nose or point *a*, in one with the radius-vector at apogee, instead of being turned 90° away from it, at the end of the first quadrant of the orbit, is just where it was, not, indeed, in one with the radius-vector, but directly in one with the centre of mean motion, several degrees to the eastward or right hand of the radius, which of course is directed to the eccentric earth. After passing this point, the flexure of the orbit begins again to increase, which increases the tendency to retro-rotate; the velocity is still continually increasing also, which increases the oppo-

site tendency of the axis to leave the attracted points of circumference behind; and the result of the antagonism is to bring the point *a* again to the radius-vector at perigee. From perigee backwards to apogee, the same process is gone through in the reverse order, along the other side of the orbit, so that, when the revolution is completed, *a* is again in one with the radius. But the variations which the moon exhibits are the effects of real *rotation*, or turning round on her axis, to the extent of the libration; and the whole process is a real *libration* or balancing on the axis, and not merely an optical deception, as some astronomers call it, though it may be true enough that the earth's eccentricity with respect to the orbit makes the libration appear larger than it would be, under the effect of the antagonist forces only. If the moon were *not* to rotate at all, the same point *a* would remain continually in one with the radius-vector. The radius-vector, however, being nothing in itself but an imaginary straight line drawn between the earth's axis and the moon's, the divergency of *a* from that line indicates a real movement of the moon's circumference past it, in the direction of the libration for the time; and the return of the point *a* to the radius equally indicates an oscillation of the moon on her axis in that direction, for the radius-vector itself never turns backwards on the moon's axis. Its motion is always forward only, along with the axis. These movements, however, are subject to the perturbing influence which act upon the moon, to the effect of changing continually the form and extent of her orbit; and so far the libration will vary considerably from what it would be in a regular and steady elliptical orbit. In a perfect orbit or circle there would be no libration.

Paradoxical as it may seem, I believe the same causes that *revent* the moon's rotation actually *produce the rotation of the earth on her axis*, and such different effects of the same cause are to be accounted for by the earth's very great degree of velocity compared with that of the moon. She flies along her orbit *thirty times* faster than the moon in hers; and this amazingly greater velocity makes her axis and outer mass leave the intra-orbital parts of the mass for the time being so much more rapidly behind than the moon's comparatively slow movement makes her axis leave her inner circumference behind, that the difference of effect, so far from contradicting the hypothesis, seems to afford strong confirmation of it. Various hypotheses have been suggested to account for the rotation of the earth, and the moon, and the other planets; but the one that seems to have been received with most favour, and to have been considered as the most probable, is that of John Bernoulli, who "has shown on mechanical principles that one impulse would produce both simultaneous

revolution in the orbit and rotation on the axis, and even calculated the precise point at which it must have been applied, so as to accord with the existing motions and velocities" of the earth and the moon.*

But Bernouilli's hypothesis proceeds on the assumption, common to him with other mathematicians and astronomers, that the planets and their satellites move about *freely* in space, under the single condition of revolving in certain definite orbits, a condition which affects their centres only, leaving their circumference and all the other particles of the mass perfectly free. But is there be any truth at all in the Newtonian doctrine of gravitation, or in the common doctrine of the terrestrial tides, all the particles of the circumference and the mass alike are affected by the mutual attractions of the different revolving bodies, those particles that are nearest the external attraction being more, and those farthest off being less affected than the centre itself, which nevertheless, consistently with Bernouilli's hypothesis, must be considered to be the only part affected at all, the attracting power passing by and through the intervening particles without giving token of its presence. Moreover, the rotatory effect of the oblique impulse which he postulates could be permanent only in the case of a body revolving freely in space, that is to say, with only its mathematical centre attracted to the centre of the orbit. But the earth is not such a body, and there is not within or reach any projectile whatever, that can be made to move along an orbit or a curve unaffected by the earth's attraction of gravitation acting upon every particle of its mass from without, and directing or controlling its movements; and it appears to me that without such an external cause of rotation as gravity supplies the rotating tendency produced by the oblique impulse would cease as soon as the movement was communicated to the whole mass, which would then fly forward with all its particles in one direction only; for, as already remarked, they cannot move backwards. All that is wanted is a power to keep them back and that is more likely to be found *without* than *within* the moving body. It is a negative power not very likely to be found in any revolving body. Though, therefore, a stone, or ball, or quiver thrown from the hand with a force acting obliquely on its centre of gravity, turns round on that centre, yet every calculation re-

* "Jean Bernouilli, dans un memoire de dynamique, ou il considere les centres spontanés de rotation, fait voir qu'une force de projection appliqué non pas au centre de la terre, mais un peu plus loin du soleil, et cela de $\frac{1}{150}$ du rayon, donneroit à la terre supposée ronde et homogène, deux mouvemens assez conformes ceux que l'on observe; pour la lune $\frac{1}{150}$. Si l'impulsion primitive eut été appliquée à des plus grandes distances de chaque centre, le mouvement de rotation seroit plus rapide. *Encyclopedie, Art. Rotation.*

specting the cause and consequences of its movements, that leaves out of account the earth's varying degrees of attraction on the different parts of the mass and their effect upon its movements, must be erroneous. To me, therefore, it seems unquestionable that, even if the earth had been originally set a-going by some such oblique impulse as Bernouilli supposes, the rotation would have stopt as soon as the whole mass was set in motion, and that it would at all events have become instantly subject to, and been modified and controlled by, the sun's attraction of gravitation, and even stopt at once if it had been in its direction incompatible with the action of the solar centripetal force. In the case supposed, however, its direction would be perfectly consistent with the action of that force, which, so far from hindering the rotation, would rather aid it; but which, at the same time, would be perfectly sufficient of itself to produce that rotation, without the primary oblique impulse supposed by Bernouilli. Suppose the earth to have been travelling straight forward in space at her present mean orbital velocity, but without turning round on her axis, when she came within the influence of the sun's attraction, that power would not merely grasp her centre, but would affect her whole mass with various degrees of force, proportional to their distances from the sun, and those attracted most would naturally feel the influence of the attraction in the *retardation* of their forward movement, while the parts farthest off would continue to fly forward with comparative freedom, and the greater the forward velocity of the mass in its orbital revolution, the more rapidly would the attracted parts be left behind, to take their turn in the rotation as soon as relieved from the sun's grasp by the lever power of the forward particles acting through the centre of the revolving body. In the rotation of a progressing body, as formerly observed, no part of it ever moves or can move *backward*; all the particles alike move forward, and only forward, and their retardation is in all cases to be ascribed *more probably* to friction, or attraction, or other hindrance from without, which are all, in their respective degrees and qualities, more or less *sufficient causes*, than to any intrinsic power of rotation, from whatever cause originating; and more especially when such a supposed hidden cause is not indispensably essential to the production of the visible effect. Bernouilli's hypothesis, therefore, is clearly at variance with Newton's rule of philosophizing, which requires us never to assume more causes of natural events than are *true*, and *sufficient* to account for the phenomena. It cannot be called *true* so long as it is improbable, and it cannot be called *sufficient*, inasmuch as it ascribes two kinds of movement in contrary directions in the same body, to the same cause, namely, the action of the centrifugal power, and

leaves quite out of consideration the antagonist influence of the centrifugal force upon the circumference of the revolving mass. It is the action of the centrifugal force that makes a body, revolving in an orbit with its circumference unaffected by a primary's attraction, turn round on its axis from east to west, or preserve its parallelism; and if the function of making it rotate in the contrary direction, from west to east, were to be assigned, as it is by Bernouilli's hypothesis, to the same centrifugal power, that power would be brought into the rather awkward predicament of acting as its own antagonist, in producing two contrary movements at the same time in the same body, and thereby neutralizing its own efforts. The hypothesis, therefore, may be fairly rejected as insufficient and untrue.

If the earth were affected exclusively by the sun's attraction of gravitation, her rotation, I believe, might be easily, simply, and sufficiently accounted for in the manner I have proposed; but she does not move alone in her orbit, and, with such a companion as the moon, the problem becomes somewhat more complicated, though scarcely more difficult; for the moon's attraction acts in the same direction as the sun's, and helps to turn the body round; and not merely *helps*, but probably she is the principal agent, her power, from her nearness, upon the earth's circumference being much greater than the sun's. To this view of the case there may be one objection started, namely, that the liquid portion of the earth's surface moves westward, contrary to the rotation, which would not happen if the moon herself were the cause of the rotation. But the earth's rotation is not the effect of the moon's action only; it is produced by the combined operation of its own centrifugal power, the centripetal power of the sun's attraction, and the moon's power; and the effect of the combined causes is to make it rotate faster than the moon revolves, so that the solid parts of the rotating mass continue to move forward, while the liquid parts, more easily affected by, and consequently more obedient to, the moon's power, are left behind, to a certain extent, by the solid parts, which slip away from below them. The waters of the ocean do not really move backwards, or in a direction contrary to that of the earth's rotation; they only, owing to their liquidity and greater susceptibility of external affections, rotate more slowly than the solid parts; but still they do participate in the general rotatory movement, passing the moon every day, as well as the dry land. "What," says Punch, "is the cause of the earth's rotation? Probably, *because one good turn deserves another.*" This jocular piece of philosophy is not so far from the truth as might be imagined; for *one good turn* not only deserves, but really tends to produce another; and the uniformity and regularity of the earth's rotations are just the

result of a long series of "good turns," every one of which has tended to help forward its successors.

The sun's rotation may be accounted for in the same way. All the planets and all their satellites act upon him as well as he acts upon them; their combined power altogether is not sufficient to move him from his place, but it may be quite sufficient to pull him round on his axis. The planets all revolve in the same direction; and their pulling power acting, as it has acted for countless ages, may have resulted at last in a mean movement of rotation, just like that of a fly wheel, which moves with regular velocity notwithstanding the irregular application of the moving power. The planets may be considered as so many men or horses pulling by so many ropes at the circumference of a monstrous wheel, which, when once set fairly in motion, continues to move of itself, with a velocity proportional to, as well as produced by, the various efforts of the combined powers. And, perhaps, if the sun himself be only the satellite of some mightier centre, his rotation will have to be ascribed in part to that also, as well as the earth's to the action of the sun.

The error respecting the moon's alleged rotation seems to have occasioned, or served at least to confirm another error respecting the *measure of rotation*, and the *equation of time*. "The length of the astronomical mean day, which is divided into 24 hours, is determined by the interval which elapses between two consecutive passages of the sun over the meridian of the same place, supposing this apparent motion of the sun to be performed with an uniform velocity. But it is necessary to observe, that our earth *does not occupy quite 24 hours in its rotation*, on account that in the same time, which it employs in revolving round its axis, it advances in its orbit towards the east about a degree in space, corresponding to 4 minutes, or more exactly to 3 minutes 56 seconds of time. Hence it follows, that the interval between two passages of a fixed star over the same meridian, *which measures the true time of the earth's rotation*, or of the sidereal day, is only 23 hours, 56 minutes, 4 seconds. The *sidereal day* is the period in which the earth makes *one complete revolution on her axis*, and is measured by the interval between two successive *transits of any fixed star over the same meridian*."

The slightest consideration should suffice to show the absurdity of such a notion. Suppose a body to revolve in a perfectly circular orbit; and its own circumference to be of exactly the same dimensions as the length of one degree of the orbit described by its innermost point of circumference. As already remarked, every revolving body has a certain definite breadth or thickness,

which causes its particles to revolve in different orbits proportional to their radial distance from the orbit's centre; and, if the orbit described by the body's innermost point of circumference, a , be exactly equal to 360 measures of the body's circumference, it is obvious that the return of a to the radius-vector will be the measure and indicator of each rotation; yet, in every such rotation, any given star will appear on the same meridian sooner than at the preceding transit, and these daily gainings, or losses rather, of the star will amount to one sidereal day in the course of the year. From this it follows most obviously, that the transit of the star is not, and cannot be, the measure of rotation, inasmuch as the measure it gives is 4 minutes of time, or 1° of space, shorter than the measure of the revolving body's real circumference, which, as already supposed, measures exactly one degree of the inner verge of the orbit. The centre of the orbit never changes its place in the slightest degree; the radius-vector is equally invariable in its relation to the revolving body; it never *falls back* a hair's-breadth; its whole length moves constantly forward, and forward only, turning round on the centre, and the centre only, and not at all round about the revolving body's axis; consequently, its relation to the orbit's centre, and to the body's axis, is precisely the same at every degree of the orbit's circumference. When, therefore, a , in rotating, turns away from the radius, the radius moves forward just *one measure* of the body's circumference, and meets a again at the end of the first degree of the orbit; and the same thing is repeated in every one of the 360° of which the orbit consists. If the body were to stand at any point of its orbit, and turn just once round on its axis, it is most obvious that the return of the same point a to the radius-vector would be unanimously acknowledged to be the completion of just *one* rotation; but, what should make a difference, when the rotation is performed, not all at once at the same point, but only gradually, minute for minute, as it were, during the body's progress in the orbit? No *reasonable* answer but the true one can be given to this question, and that true answer is, that there is not, and cannot be any difference; and that in a perfect orbit, with a revolving body describing equal areas in equal times, which, in that case, would be with perfectly uniform velocity, the radius-vector indicating the transit of the sun within the orbit, and not the transit of the star outside, would be the true measure of rotation.

The phenomenal relations of the heavens and the earth are the same, whether we ascribe them to the earth's orbital movement round the circuit of the heavens, from west to east, or to the circumvolution of the heavenly sphere itself, in the opposite direction, or from east to west, round the earth at rest in the

centre of the universe. Suppose then the earth to remain at a fixed point of space, while the sphere of the heavens turns round about it, and to turn round on its own axis 360 times during the period of the revolution of the stars in the ecliptic; the sun all the time remaining in the centre of the orbit, in one with N outside, or, as it were, straight south of N, north. Commencing its revolution at N (fig. 5,) and moving from east to west, or to the right hand, while the earth at the same time turns round on its axis from west to east, the star will continue to move always further and further away from N, to the extent of one degree, during each of the earth's rotations. But the earth is fixed in the same point of space, and, so long as it is so, its rotation can only be complete when the same point of its circumference *a* returns to the fixed point N; and the opposite point *b*, 180° distant, again faces the sun, and is in one with the radius-vector, or straight line that connects N and S. In making this return, *a* will every day, or in every turn, be in one with the off-moving star four minutes sooner than it reaches N; consequently, its rotation will then be incomplete to the extent of one degree of its own circumference. On the second day, *a* will point to the star 8 minutes before it reaches N; on the third day, 12 minutes; and so on through the whole series of the earth's 360 rotations or days, during which it will have seen the star 361 times, the sidereal day being 1-360th part shorter than the solar day, which measures the earth's complete rotation. It is, however, perfectly obvious and undeniable that in this case the difference is occasioned by the star's moving away from N, and not by N's moving away from the star; consequently, the star, by so moving away from N to an always increasing angular distance, presents itself to the earth's point *a* four minutes of time sooner in each rotation, or every day. It is, on the other hand, just as perfectly obvious and undeniable that the rotation is incomplete till *a* return to N; and that being so, either N itself or a straight line drawn between it and the sun, must and can be the only true index of the rotations. Now, just reverse the process, and let the star stand still at N, while the earth revolves from west to east, rotating as before, and carrying of course its radius-vector NS along with it, which radius will revolve round S, as its pivot of rotation. When the earth completes her first quarter, the star, remaining at N, will be in precisely the same relation of place to the earth, as it was, when it (the star) had reached its own first quarter of rotation, while the earth was remaining at N; and so on throughout the whole revolution of the earth in her orbit, which is precisely the converse of that of the stars, their mutual relations being precisely the

same in both cases. From this it follows inevitably that it is the sun's transit, indicated by the passage of the point *a* or *b* across the radius-vector, and not the transit of any star over any given meridian of the earth's surface, that is the true measure of the earth's rotations, or at least that would be so, were the earth's orbit a perfect circle, along which she moved with uniform velocity.

Suppose the earth, instead of rotating 365 or 360 times in each orbital revolution, were to rotate only *once*. By rotating *once*, however, be it observed, I do not mean that she should keep the same point of her circumference constantly on the radius-vector, looking to the sun; on the contrary I really mean to say what the word expresses, that she should indeed turn once round about on her axis *like a wheel*, carrying every point of her circumference past the radius-vector, and across the orbit. Of course, as already remarked, and as admitted by all astronomers, the results would be precisely the same, whether the star revolve round about the heavens from east to west while the earth stands still at N, or the earth move round in the contrary direction, from west to east, while the star stands still. Let the earth, therefore, for the present be considered as standing still at N, and let the star revolve to the right, or from east to west. By the time the star reaches the first degree to the right of N, the earth will have turned on her axis one degree in the opposite direction, making together a difference of *two* degrees; and this being repeated at each degree, the star will make its transit over the same meridian which it left behind at N, when it has only gone round *half its circuit* of the heavens, and the earth has turned only *half round* on its axis. After a similar process, during the other half of the star's revolution and the earth's rotation, the star will make a second transit over the same meridian, or in other words, the star and that meridian will again be in one at N, after completing their respective circuits. But it must be perfectly obvious, that in this process the earth has turned round on its axis *only once*, and measured its complete rotation by carrying every point of its circumference, without exception or shortcoming, past the radius-vector and the sun; and consequently that the radius-vector and the sun's transit are the sure and only measures and indications of complete rotation, while on the contrary, the star and its sidereal day falls short of that complete measure by no less than a half rotation in this particular case. If the earth were to rotate twice, the star would have three transits; and, in short, for every number of the earth's complete rotations in a year, the star will make one transit more, which is just the proportional value of its shortcomings with respect to the rotations. Let the star now stand still at N, while the earth

revolves from west to east, turning round on her axis *once*, that is, at the rate of one degree of her circumference for one degree of her orbit, and precisely the same results will follow, without the slightest difference in the phenomena. As before, the star will fall so far short as to make *two* transits during the revolution; or *one* transit more than any number of complete rotations the earth may make. And by their own admission of precisely similar results in the two cases, astronomers are precluded from objecting to this conclusion of the argument, which entirely confutes their doctrine of the sidereal day's being the true measure of the earth's complete rotation.

It is true, indeed, that the outermost point of the earth's circumference describes a much larger orbit than the innermost point, and from this fact astronomers infer that the point *a*, after really completing one rotation, will take four minutes more to make up the difference. But, it has been shown already, that this difference in the dimensions of the orbits has no effect whatever upon the *rotation* of the moving body; and that it only causes the axis to move forward more rapidly, and change its place in relation to other bodies, while, with respect to itself, all the parts of the body's internal mass and external circumference remain in precisely the same relative positions, whether they rotate or not. That is to say, if the body do not rotate, that relation of the parts to the axis remains absolutely invariable, however much the axis itself may change its place in the orbit, and its relation to other bodies; if, on the contrary, the body rotate, the rotating parts change their places just precisely to the same amount in the same time, as they would, if the axis were to stand still; the whole effect of the more rapid motion of the outer circumference being *not* to make the circumference rotate more rapidly round the axis, but to make the axis itself move forward so much faster than the inner point of circumference as virtually to describe a circle round that very point, instead of that point revolving round the axis. And this is fully confirmed by what has just been said in illustration of the converse movements of the heavens and the earth.

The variation in the length of the solar day is ascribed to the difference of the sun's velocity in different parts of his orbit; but the only way in which such different degrees of velocity could affect the length of the day, would be by making him, or more correctly, the earth turn more rapidly, or more slowly, as the case may be, round on her axis; and thereby to make her rotations not *uniform*, or of precisely the same length. In opposition, however, to this legitimate inference from the alleged cause, astronomers say that the earth's rotation is precisely *uniform*, and is measured by the sidereal day, which, says Mr Barlow, "is the most uniform of all astronomical periods, neither

observation nor theory having yet detected in it the least variation." By "uniform" is meant that the successive transits of the same star over the same meridian of the earth's surface happen after always precisely equal intervals of time; but it must be obvious from the slightest consideration, that if the solar days are not uniform, neither can the sidereal days be so; for the meridians over which the sun's and the star's transits are made are the same, or at least corresponding meridians of the same surface of the same revolving body, and consequently liable to the same variations and disturbances in all respects. If, therefore, the "uniformity" of the sidereal day be an observed and positively ascertained fact, some other cause of the variations of the solar day than those assigned by astronomers must be sought for; and that cause is most readily to be found in the *ellipticity* of the earth's orbit, and the sun's eccentric place within it. The direct result of these circumstances is that the earth's radius-vector almost constantly subtends a continually varying angle to the orbit, sometimes approaching it on one side and sometimes receding. As the earth revolves from her aphelion point, the radius-vector diverges from the perpendicular, and gradually approaches the west side of the orbit, forming an acute angle with its vertex to the north, and consequently meeting the earth's meridians proportionally sooner every day. Soon, however, it begins to recede, and open out from the orbit, and consequently to make the earth's meridians take a proportionally longer time to reach it in their rotation. The same process is repeated four times, in converse order however, during the whole orbital revolution, and sufficiently well accounts for the difference in respect of "uniformity" between the sidereal and the solar days; for the stars outside, in respect of relative position, are quite unaffected by the variations of the radius-vector. Having no means of making accurate observations for myself, I can only reason on the data supplied by others. Taking, therefore, the common tables for the equation of time, I find them to agree remarkably well with the *cause* which I have now supposed. From this it will follow that mean and apparent solar time will coincide or equally show true time, only at those points where the radius-vector is perpendicular to the orbit. In a perfect orbit or circle, the radius-vector would be invariably perpendicular to the orbit, and consequently would always be the true index and measure of the planet's rotations, while the star outside would fall short of that true measure by more than three minutes every day.

In a popular treatise on science I find it stated that "any meridian on the earth will revolve from a fixed star to that star again in exactly the same time as if the earth had only a diurnal motion, and remained always in the same part of its orbit."

Undoubtedly this would be true, *if* the earth were really to remain "always in the same part of its orbit;" but the case is completely altered when she moves in the same direction as she rotates to a constantly increasing angular distance away from the star, for then the star will be seen, or will make its transit proportionally sooner every day, and, consequently, when the rotation is so far incomplete. "But," our author continues, "with respect to the sun, as the earth advances almost a degree eastward in its orbit in the same time that it turns eastward round its axis, it must take more than a complete rotation before it can come into the same position with the sun that it had the day before." This would be perfectly true *if the sun moved away from his place* so much proportionally every day as to require an additional turning of the earth to overtake him; but *the sun stands positively still*, and the earth's meridians meet him precisely in the same *place* every day, though not always at precisely the same *time*; for his relation to the earth is invariably the same, excepting to the small extent occasioned by his eccentricity and the ellipticity of the earth's orbit, with which points, however, we have nothing to do at present, and it will answer our purpose equally well on both sides of the question, to consider the earth's orbit as a perfect circle with the sun in the centre. This relation of the sun to the earth's axis and to the radius-vector that connects them, is entirely unaffected by the earth's movement in her orbit, and, were the earth's orbit a perfect circle, the sun and the radius-vector would be the true measures of the complete rotation in respect of *time* as well as of *space*. But all this I have shown fully already. Would the wheel of a cart, which is always moving forward, be considered to have made a complete rotation, if the spoke that was perpendicular to the ground at one turn, should fall short of that perpendicularity at a point in advance of the former point of the ground by the exact measure of the wheel's circumference? Say the wheel's circumference measures 15 feet, and it were to roll along a road divided exactly into marked spaces of 15 feet each, would it not at each mark present constantly the same spoke or point of its circumference perpendicularly to the ground? Why then should not the earth do the same, when the marks of her travelling path are as exactly measured, and as distinctly marked by the sun, as any points on any road can be? The earth's orbit, considered as a perfect circle, is divided into 360 perfectly equal degrees, with which the sun is connected by an equal number of radii at the same precisely equal distances; his transits, therefore, must be the best, the surest, and, indeed, the indispensable signs of the complete rotation of a round body moving along the circle's circumference. Moreover, the extension of

the sun's 360 radii beyond the earth's orbit to the concave celestial sphere, "the firmament of heaven," would divide the whole visible universe into 360 apparently equal parts; and were any globe or mass of matter whatever to revolve in any one of the infinite multitude of orbits that might be drawn round the sun in the centre, and to rotate on its axis 360 times during each complete orbital revolution, then most assuredly each of its rotations would be complete only when the same points of its circumference, 180° distant from each other, or diametrically opposite, respectively returned to their places on each of the protracted radii, with their connecting diameter in one with the radius for the time; the same point facing the sun always at the end of each rotation, and the same opposite point always facing the corresponding point marked on the face of heaven by the protracted radius. On the contrary, every star on the ecliptic would be passed in its turn, and, in consequence of the angular distance continually gained by the revolving body, would fall proportionally short of the true measure of the body's rotation, making 361 transits when there were only 360 rotations.

What seems to have confounded the ideas of the writer from whose book I am quoting, and of all other astronomers, is that the sun turns round on his own axis in 25 days 10 hours, but it requires 27 days and upwards to bring back the same point of his circumference to the earth's radius-vector; *because*, while he is turning round from east to west, the earth is advancing in her orbit *in the same direction*, and, consequently, is always gaining upon the sun, who remains in his place, and is obliged to take more than a complete turn before the same point of his circumference can overtake the advancing earth's radius-vector. But this has nothing whatever to do with the earth's rotation, it being a matter of perfect indifference what part of the sun's circumference may present itself to the earth's meridian. Whether he rotate or not, the result, so far as the earth and her noons are concerned, will be the same; for it is the radius-vector directed to the sun's centre, and not a particular point of his circumference, that marks the moment of transit. But, owing to the movement of the two bodies (sun and earth) in the same direction, the earth will see the sun's whole circumference *one time* less than the number of complete rotations which he makes in a year, his rotations *as a fixed body* being measured and indicated, not by the flitting earth's radius-vector, but by his presenting the same point of his circumference again to the same equally *fixed* point of the heavens; that is to say, for every fourteen complete rotations on his axis, the sun makes only thirteen transits of the earth's meridians, not through any fault of his own, but owing entirely to the earth's moving away from the

index of his rotations. The sun and the stars are alike perfectly fixed and immovable in their relations, and these their mutual relations are never in the slightest degree affected by the earth's movements. The changes of place which they, and particularly the sun, *seem* to undergo, are *apparent* only, and not *real*, and are the result exclusively of the earth's own continual change of place, and therefore the indicator of the sun's rotations must be a point of the heavens as invariable, or as little variable in position as he is himself, provided always he turn round on his axis with a uniform velocity, which there seems to be no reason to doubt. But if the sun and the earth were to change places and conditions, the earth becoming the fixed centre of the orbit, and the sun revolving about her as a planet or satellite, the case would be entirely different, for then the fixed and invariable axis of the earth and the sun's equally invariable radius-vector would become the true measure and indication of the sun's rotations, while, on the contrary, the star or other fixed point of the heavens, by which they were previously measured and indicated, would fall continually short of the true measure in proportion to the angular distance to which the sun would be continually moving away from it; and what would happen with the sun in such a case does most certainly happen in the case of every planet, satellite, or other body whatsoever moving in an orbit; namely, that when the orbit is a perfect circle, the radius-vector connecting the body's axis with the centre of the circle will invariably subtend or form a right angle with the orbit, and the centre itself will remain invariably in the same place, and this invariableness of the centre and the radius must most entirely preclude the possibility of rotation on the part of a circumference which keeps the same point continually in one with them. To my own judgment this is so perfectly evident, that I can never cease to wonder how any body could ever have doubted it, or gone so far wrong as to maintain the contrary received opinion.

An error of the like kind prevails respecting the true measure and indication of the moon's revolutions round the earth, as I find it stated in the following extract:—"The moon *performs its revolution round the earth* in 27 days, 7 hours, 43 minutes, 11 seconds, usually called a *periodical month*. It is to be observed, however, that the moon employs more than this time to return to the sun after each conjunction. The cause of this difference is, that the earth, and consequently its satellite the moon, advances in the ecliptic, while the moon is describing her orbit; so that before the moon comes into the same position relatively to the sun, 2 days and about 5 hours elapse beyond the time required for completing a revolution round the earth. The whole time occupied in returning to the sun is 29 days, 12 hours,

44 minutes, 28 seconds. This interval of time is called a synodical month, or lunar month. It commences from the moment when the moon is directly between the sun and the earth, in which position the moon is said to be in *conjunction*."

After what I have said already, this passage will require little comment. It is positively untrue, in so far as it asserts or implies that the earth's advance in the ecliptic occasions such a change in her relation to the sun, as to require an addition of nearly two days and a half to bring the moon round to the sun, after she has *completed* her revolution round the earth. The earth's relation to the sun is *invariable*, (except, as already so often mentioned, to the small extent occasioned by the ellipticity of her orbit). She finds him *in the same place* positively every day and every month, while, on the contrary, it is the stars to which our author most erroneously ascribes this invariableness, that experiences the change of relative position occasioned by the earth's progressive movement in the ecliptic. It seems to me the plainest dictate of common sense, as well as of right reason, that if I were to place a dozen of posts round a circle on the ground, to represent the stars, and one in the centre to represent the sun, and then to walk round the circle *within* the line of posts, I should pass every one of them in succession, and change my angular position with respect to each of them at every step of my progress, while, with respect to the solar post in the centre, the relation of the perpendicular axis of my own body to that post would be invariable, always at precisely the same distance, and with precisely the same right angle subtended on each side by my radius-vector with my orbit; and that, in consequence, if I were, at each of the twelve posts, to turn once round on my own axis, commencing with the solar post and the radius-vector in line with my nose, my rotation surely would not be complete till I found myself return to the same position, with my face direct to the sun; while, on the contrary, the post which I had last left behind, and the corresponding post 180° distant, would be seen to have changed their places to an angular extent corresponding to their positions in the circle, and pass my nose and back proportionally sooner than the completion of my rotation. And if, instead of making the rotation all at once at each post, I were to turn myself in the same direction gradually and proportionally, degree for degree, during my progress from one post to another, the result would most certainly be precisely the same. Is it not therefore more reasonable to consider the invariable right angles of the radius-vector, rather than the continually changing angles subtended by the stars, as the true indications of the completion of the planet's or satellite's rotation? Now look to the diagram, fig. 6, which will answer equally well to illustrate the subject of the earth's rotations and the moon's revolutions; the

line of stars representing the ecliptic or concave circle of the heavens ; the continuous ring, the orbit of the earth ; and the body in the centre, the sun or other primary, as the case may be. When the planet or satellite is in its place on the orbit at N, it is then in line with both the star N and the sun, and were it to turn round on its axis at that point, both the sun and the star would equally indicate the completion of the rotation, because they are both, as well as the straight line that connects them, at right angles with or perpendicular to the orbit. At the same time, the straight line, forming in part the planet's radius-vector, continued across the orbit, points directly to the star S, at the angular distance of 180° from the star N. Then move the planet to the octant point NW. The diametric line of the orbit running through the planet's axis and the sun will then point to two different stars, each at the angular distance of 45° from the opposite ends of the line NS ; but the sun will remain *just where he was, in precisely the same place* in the centre of the orbit, at the same direct distance, and still subtending with his radius a perfect right angle at the planet's axis on the orbit. The same process repeated at each octant or at each degree of the circle will shew precisely the same results. At the 180 degree of revolution, the planet will be in precisely the same relation to the star S that it formerly was in to the star N ; which of them is to measure the rotation now ? They both alike measure it exactly, *because* they are once more in a rectangular position with respect to the axis on the orbit ; and *because* they have fallen short of the true measure of rotation to the extent of 180° , or half the planet's circumference each ; so that, with respect to the planet, they have virtually come into each other's places. Precisely the same results would follow were the planet to stand still at N, while the circle of the stars revolved, if that were possible, round the centre of their circle, and then they would shew unquestionably that it is only where the planet's protracted radius-vector touches the circle of the heavens that the star which may be for the time at or opposite to that extremity of the radius, can indicate the completion of the planet's rotation. If, while the planet stands at N, and rotates without revolving, will the star NE be the true measure of rotation ? No, certainly. Then just as little can the star N be the true measure of rotation when the planet revolves to NW. Let the small circle which has hitherto been considered as representing the earth's circumference now be considered to represent the moon's orbit, with the earth in its centre, and every thing that has been said will apply to the moon's case, as exactly as if she were really, what she is virtually, a point of the earth's circumference. She does not lag behind the earth as the latter progresses ; she is some-

times as far before the earth as behind, her distance being not very variable, and consequently her revolutions must necessarily have the same measure of completeness as the earth's rotations. Why, then, should we resist the conclusion to which all this leads, namely, that the received opinion of astronomers on the subject of the rotation of the planets and their satellites is erroneous? The only plausible answer I can anticipate is, that Galileo, and Newton, and La Place, have sanctioned that opinion, and their authority is better than mine. But is it better than right reason and common sense together?

In the treatise on "Astronomy" published in "*The Library of Useful Knowledge*," I read, "We find not only that the duration of a sidereal day is constant, but that during every part of it the rotation goes on uniformly; or, in other words, *that the heavens revolve round their axis continually with an uniform velocity*.—The interval between the successive appearances of the sun upon the meridian, or from noon to noon, is necessarily longer than that between those of a star; for as the motion of the heavens is from east to west, and the proper motion of the sun from west to east, the sun on each successive day, when the point of the heavens where he was at noon on the day before returns to the meridian is to the eastward of that point, and consequently to the eastward of the meridian; and he, therefore, only returns to the meridian after the rotation of the heavens has continued for some additional period, long enough to bring his new place to the meridian, &c. The solar day is longer than the sidereal day in consequence of the motion of the sun eastward in his orbit, &c." I have quoted these passages, not for the purpose of making any direct comment upon the "scientific truths" which they embody; for such a comment as they require has been already anticipated, or will be still introduced elsewhere. But how could an author who seriously believes in the truth of the Copernican system of the universe deliberately affirm, to use his own italics, "*that the heavens revolve round their axis continually with an uniform velocity*;" or that "the sun moves eastward in an orbit?" Such a way of speaking must inevitably puzzle and perplex the readers of his book, as much as it seems to have puzzled and perplexed himself; for his ideas on the subject of the sun's and the earth's movements must have been utterly confounded when he affirmed to be positively true in fact, what could only be true if the earth were really to be placed in the centre of the orbit, and the sun were to be a planet revolving round about her, namely, that the star outside, and not the sun inside, is the true indicator of the earth's rotations, and of the moon's revolutions. But, when the case is reversed; when the sun takes his proper place as the fixed centre of the orbit, and

the earth becomes the planet in his stead, all that was *true* before, in respect of his rotation and revolution, becomes *false* now ; and it is from overlooking the consequences of this change of circumstances, that the error I am combating seems to have originated ; and to this confounding of ideas, this mistaking of things different for precisely the same, the long continued prevalence of so very palpable a set of errors is to be ascribed.

Having, therefore, now finished my own case, and brought forward such arguments, proofs, and illustrations, as seem sufficient in my judgment to establish the *truth*, or what I believe to be the truth, I shall now proceed to examine such of the principal arguments and illustrations usually brought forward in support of the received opinion, as I have not yet had occasion to notice. I might, indeed, soon make up a large volume with the materials that superabound upon this subject, but I must be content at present with such as seem to be of sufficient importance to deserve notice. With respect to the *principles* of the whole question, the *invariableness of relation* of a planet's or satellite's axis and radius-vector to the primary's centre, and the ascription of every change of relations between the moving body's circumference and its radius-vector, exclusively to the rotatory movement of the revolving body itself, I have never had the smallest doubt or wavering since I read and understood Galileo's illustration of the subject, which I shall now present to my readers.

In his *System of the World*, Dialogue iii. he says, “ Naturally, *without any moving cause*, a body freely suspended and carried round the circumference of a circle, *immediately of itself acquires a rotation*, that carries it round its own centre in a direction contrary to the motion which carries it round the circle, and with such velocity that both of these motions of revolution and rotation are completed in precisely the same time. This may be admirably illustrated by the following experiment. Take in your hand a basin of water ; and turn yourself round on your feet, and you will see the water begin to turn itself round in a direction contrary to that of the basin, and finish its rotation at the same time with your and the basin's revolution. But, if you consider the matter attentively, you will perceive that the effect produced is nothing real, but only a mere appearance ; that, what seems to be a rotation on its own axis, is really no motion at all ; and that the water remains immovable in respect of every thing stationary beyond the limits of its orbit ; presenting the same side or hemisphere continually to the same side of the room, or field, where the experiment is made, or to the same part of the sky. If, on the other hand, it be compared with the basin and yourself, who are both moving, it will be observed to change its direction,

and to rotate with a motion contrary to that of yourself and the basin ; so that it may be more truly said that the basin and yourself gyrate round the immovable water, than that the water rotates within the basin." So says Galileo ; and truly, had all his other experiments been followed by such inferences as this, he must have occupied one of the lowest places in the ranks of science, if any place at all, instead of one of the highest. He must have been labouring under some strange delusion, when he persuaded himself to believe that a body which was visibly rotating before his eyes, and making all the points of its circumference in succession pass its radius-vector, or the straight line between its own centre and the centre of its orbit, and continually changing their distance from that centre, all the way round, was nevertheless immovably at rest. He seems indeed to have escaped the blunder of some of his successors, and to have been quite well aware that there were only *two* possible ways in which he could see a body all round, namely, by going round it himself, or having it turned round about before him ; and accordingly, when he inferred from his experiment that the water did not rotate, his only alternative was to suppose that he himself and the basin must have gone round about the water. But it seems not to have struck him that this was impossible without leaving his central position and crossing the orbit twice, once in going to the outside and again in returning. Some of the schoolmen of old were of opinion that angels could go from one place to another without passing through the intervening space, and not without some shew of reason, for angels were supposed to be purely spiritual beings, without relation to time and space. Less reason than even this had Galileo for his opinion, when he supposed it possible for a heavy material substance like his own body, occupying a fixed position in space, to perform a gyration round about a distant point or body, not only without going through the intervening space, and measuring out by his movement the line of gyration, but even without ever stirring from the spot he occupied ; his whole process of circumgyration being just as purely spiritual and imaginary as the angels' transit, and virtually the same thing as a planet's performing an orbital revolution without going round about the space which its orbit incloses, or through a single one of the 360° of which its orbit consists. Homer, the prince of poets, is said "sometimes to snore as well as nod ;" so may it be said of the great "Tuscan artist," *aliquando bonus dormitat Galileus*.

Galileo would have discovered his error at once if, instead of water, he had put into the basin a quantity of meal, flour, sugar, sand, earth, gravel, or any other sluggish material, and made it revolve, as before. In this case the matter would lie

still in the basin, presenting, like the basin itself, the same side of its circumference continually to the centre of the orbit. Why does it not rotate or *seem* to rotate like the water? If, as alleged, the water does not rotate, does the more sluggish material, with the basin that contains it, perform that operation, by virtue of a rotary power naturally inherent in them? These materials exhibit the result which astronomers ascribe to rotation, yet keep all the parts of their circumference in precisely the same relation to the radius-vector, and to the line of revolution described by the central axis of the mass; while the *non*-rotating water carries every part of its circumference in succession past the radius-vector, which may be represented by a stick laid across the basin, and the line of revolution, and through all the various degrees of distance from the centre of the orbit, between its inner and outer edges, as determined by the diametric breadth of the moving body. Every point of the water's circumference is seen successively diverging from the line of the centre's orbital revolution, and the sum of all these successive divergences amounts to a complete rotation, or turning round of the body on its own axis or centre. It is indeed impossible to account for the different results of the experiments when performed with water, from those produced by the using of other substances, but by admitting the real rotation of the water, whose liquidity enables its particles to slip past each other in obedience to the impulse of the moving power; and denying the rotation of the basin and its more sluggish contents, whose particles are kept in their places, not by an inherent rotatory power, but by their *want of power* to overcome the friction that would instantly ensue among themselves, as well as between them and the sides of the basin, were they to attempt to move round about their centre like the water. Their adhesion, cohesion, vis inertiae, weight, or gravitation, is too great to be overcome by the impulse of the moving power, while the lighter particles of the liquid and unresisting water fly forwards at once and continually till they get, all in their turn, round about the axis.

The experiment may be varied by placing a stratum of gravel in the basin, and pouring the water above it. Then make the basin revolve, and the liquid water will be seen as usual, moving away round, while the sluggish gravel lies still. Which of the two, the movable water or the immovable gravel, is the more likely to rotate? The water unquestionably. Astronomers, however, think differently, and say, or at least to be consistent ought to say, that it is the gravel, which rotates on its own axis, and thereby "*brings* the same point of its circumference continually back to the radius," while the water keeps all its particles *parallel* to themselves. But the gravel certainly does not possess any inherent power of rotating in that direction, while the water

possesses not only the power, but also, what the moon has not, the *freedom* to rotate in the opposite direction; and using its freedom, away it flies round and round about continually, the particles of its circumference, and generally of its whole mass, changing their place-relation to the axis and to the radius-vector, and to the orbit and its centre, at every instant of progression. Even when water is used by itself in the experiment, a portion of its particles adheres to the sides of the basin, and remains behind, while the rest of the mass moves round about. According to the astronomic doctrine, the reason of this is, that the particles so adhering, and lying still with the basin, *rotate* or turn round on the water's axis, in that direction, while the rest of the water stands still. "*Credat Judæus Apella; non ego.*"

Galileo says that a body suspended freely in space naturally without any moving cause acquires a rotation round its own centre. But a moving cause there must be, and the cause of the water's rotation is this. The different parts of the water's mass have different orbits of revolutions, and, if they were to keep to these orbits, there could be no rotation, and the same point would be constantly presented to the centre of the orbit; but, as they are all carried round their orbits with precisely the same degree of velocity, by virtue of continued impulse of the same single moving power, that point of the circumference that is inside of the orbit, and nearest the experimenter, can find space for its journey only by going outside of its orbit, and consequently turning itself and the whole mass round on its axis to the same extent, while the outer portion of the circumference as necessarily falls within its proper orbit, leaving the centre alone to follow the mean orbit of the mass. In this way the three points, namely, the outermost point of circumference, the innermost point, and the centre, travel precisely the same distance, in the same time, with the same velocity; thereby causing a rotation of the body round its own axis; or, what is the same thing, preserving the perpendicularity and parallelism of its particles, while the axis is continually changing its place. This may be further illustrated in the following manner.

A body revolving in an orbit has a certain definite breadth, whereby it happens that its outside, or the outer part of its circumference is farther distant than the inside or inner part of the circumference from the centre of the orbit. Consequently, in travelling round the orbit these outer parts have a longer space to run through, which they can only accomplish by means of a greater degree of velocity. But, if it were required that the outer and inner points of circumference, A and B should proceed with neither more nor less than *precisely the same degree of velocity* as the centre C, and yet complete their revolution in *pre-*

cisely the same period of time, how would they be able to perform so marvellous a feat? Suppose the eight circles (fig. 7) to represent a globe revolving in a orbit round E. Suppose the centre of the revolving globe to be precisely 240,000 miles from the centre E; and its own diameter to be just 2000 miles. Its centre, therefore, will describe an orbit of 1,440,000 miles in circumference; but the corresponding orbits of the points A and B, which are each 1000 miles from C, will be respectively 1,434,000 and 1,446,000 miles. To get through these orbits, *in the same time*, A would have to travel with a less, and B with a greater velocity than C; or, if they did not, it would happen that when C completed its revolution, A would be 6000 miles in advance, and B 6000 behind it; but cohesion of the parts prevents them ever getting farther away from C than 1000 miles; and, therefore, they must proceed in some other way than by orbits concentric with C's. In each octant of the supposed case, the difference in the lengths of the three octants is 750 miles; A's octant being so much shorter than C's, and C's so much shorter than B's. Suppose their revolution to be effected by means of a force acting in the direction of the centre C, or in such other way as that all the three points shall travel with precisely the same degree of velocity. When the revolving mass finishes its first octant and reaches the position No. 2, A will have run through its own proper octant, and 750 miles more, for which it finds room by running to that distance *outside* of its orbit; while, on the other hand, B saves a like distance by falling 750 miles within its orbit; so that all the three points have travelled precisely the same distance in the same time, each 180,000 miles. The points *a* and *z* now come into play, as the outer and inner points of circumference; when the mass completes its second octant, *a* is found, like A, to have run another 750 miles outside of its orbit, while *z* has fallen within its orbit to the same extent. The points *b* and *y* now come into play, and repeat the operation, and so on, through the remaining octants, so that when the revolution is completed, A has made up its deficiency of 6000 miles by revolving or rotating round C, whose external circumference, containing the points A and B, is exactly of that dimension; while, on the other hand, B has saved 6000 miles, by constantly falling back in the opposite direction; and the general result of the process is that the three points have travelled precisely the same number of miles; C along the mean orbit of the mass; but A and B along two new orbits, each of precisely the same dimensions as C's, but drawn round different centres, corresponding to their respective diametric distances from C. Their orbits are indicated in the diagram by the two dotted circles. In no other way could the feat have been accomplished, than by A and its successors *a*, *b*,

c, &c., in succession, turning the mass round on its axis to the extent of one-eighth part of its circumference during its progress along each octant of the orbit, while B and its successors were simultaneously falling back to the same extent, in the opposite direction. Whatever be the size of the revolving body, and its proportion to the circumference of its orbit, the process and the result will be, in all cases, precisely the same. It may be scarcely necessary to add, that what takes place with the octant points, happens equally with every one of the body's intervening points, all of which, at every instant of progression, take precisely the same course as the octant points specially referred to. At every instant each of them takes a step forward, while the axis is turning in the opposite direction, without carrying them back to their original places, relatively to itself.

This great mistake of Galileo's, later astronomers and mechanicians have fully adopted; and, believing the moon to be fairly represented by the water in the basin, and that the water so placed does not rotate, they have very naturally indeed, but too hastily, jumped with him to the conclusion, that, to enable the moon to "*bring* the same point of her circumference continually *back* to the radius," she must have a power to rotate, and does rotate, in a direction "*contrary* to that of her revolution." "*Contrary*," the direction of this alleged rotation must be called, for unless it were "*contrary*" it could not be true; and yet, "*contrary*," as it is called, it is not the less precisely in the *same direction* as the line of revolution; for it is from west to east, and the revolution is so too. Galileo might have taught them better, for he rightly says, that the water's visible rotation in the basin is *contrary* to the direction of the basin's orbital revolution; and if that be correct, as it unquestionably is, then must the moon's alleged rotation in the opposite direction, from west to east, be not contrary to, but in the *same* direction as, the revolution; and, being in the same direction, its inevitable result, if it existed, would be the presentation of every part of her circumference in succession to the earth. As a wheel, moving along a rail, and rolling forward in the same direction, carries every part of its circumference in succession to the rail, and past a straight line drawn across it through its axle perpendicular to the rail, so would the moon, revolving as she does, and rotating, as alleged, in precisely the same way as the wheel, carry every part of her circumference past her radius-vector, and all round about. But, besides adopting Galileo's error, some of them have made a far greater mistake of their own, for they have supposed, what he did not, that there is a *third* possible way of an observer's seeing the whole circumference of a globe, namely, by having it carried round about him without turning round on its own

axis, or any other point or pivot of revolution in his presence. Such a result, without rotation or turning round, is plainly impossible, and the object of all my arguments and experiments is to show that it is so. In this respect they have acted quite in the spirit of the Ptolomeans, who went on continually adding new cycles and epicycles, to explain the phenomena of the universe, till Copernicus displayed to their astonished eyes the simple truth, and demolished the complicated fabric that had been the work of many ingenious minds during many ages. The rotation which astronomers ascribe to the moon is just as purely hypothetical and groundless as any Ptolomean epicycle; yet has this doctrine been allowed to remain for almost two centuries a foul blot on the temple they have reared to the glory of physical science.

In the article ASTRONOMY, in the Encyclopædia Edinensis, (I. 510,) said to have been written by "George Buchanan, Esq., Civil Engineer, Edinburgh," the moon's rotation is thus described and demonstrated:—"From the motion of the solar spots has been inferred the rotation of the sun on his axis. The same conclusion is drawn in regard to the moon, from the apparent rest of her spots. For, as we go round and round a building when we wish to have a view of it on every side, in the same manner would the moon present to us, in succession, every portion of its surface, if, without moving on its axis, it only revolved round the earth, *the appearances being evidently the same as if the earth went round and round the moon at rest.* Thus, if a spectator on the earth should observe a remarkable spot, S, (fig. 8,) on the centre of the full moon at M, he would *evidently* lose sight of it by the time the moon, *if immovable on her axis*, arrived at her quarter at *m*; and another spot, *s*, which he did not at first observe, would now occupy the same centre position; and in order that the same spot as at first should still be observed on her centre, it would be absolutely necessary for her to make a quarter rotation in a direction contrary to that of her revolution. When the moon, therefore, in revolving round the earth, still presents to us a figure whose general appearance, though extremely irregular, is always the same, and which must on this account be undoubtedly the same half of her surface, we may be assured that *the moon has really a rotation on its axis*, in a direction *contrary* to and keeping exact pace with her revolution round the earth."

To the eye of common observers the sun and the moon appear to be both alike satellites of the earth, and, as such, to go round about the whole heavens in very nearly the same track. But, if the one of them, the sun, turn on his axis, and, by so turning, show a succession of spots flitting across his disk, should we not

expect to see the same effect produced by the rotation of the other moving body, the moon, in circumstances so precisely similar? No, says Mr B.; for, though the flitting of the spots across the sun's disk is the effect, the sign, and the evidence of his rotation, and, consequently, were he not to rotate, these spots would stand still; yet, is the standing still of the spots on the moon's face the effect, the sign, and the evidence of her rotation also! But, on what principle he could found such an answer is anything but evident; and it is astonishing that the statement of his own argument did not make him doubt the truth of the received doctrine on this subject. To make bad worse he proceeds thus; "As we go round and round a building, when we wish to have a view of it on every side, in the same manner would the moon present to us in succession every portion of its surface, if, *without moving on its axis*, it only revolved round the earth, the appearances being *evidently the same*, as if the earth went round and round the moon at rest." Such is a specimen of the *reasoning* with which astronomers attempt to justify their paradox; and such reasoning has been deemed sufficient to overrule the irrefragable evidence of non-rotation, supplied by the fact of the moon's presenting the same face continually to the earth. So far, however, are the movements, which Mr B. compares, from being "evidently the same" in their results, that by a very simple proof we shall find them to be totally different. I cannot, indeed, conceive, and should like much to be told, *how* it is possible for every portion in succession, of the surface of any body whatever, whether revolving in an orbit, or stationary, to be seen by any observer, but in one of two ways: either by the observer's going round it, or by its turning round on its own axis, or some other point or pivot of revolution, in the observer's presence. This alternative affords the true opposites that Mr B. should have contrasted, and not the observer's going round the body, or the body's going round the observer, without "moving on its axis."

"If," proceeds Mr B., "a spectator on the earth should observe a remarkable spot, S (fig. 8), on the centre of the full moon at M, he would *evidently* lose sight of it by the time the moon, *if immovable on her axis*, arrived at her quarter at *m*; and another spot, *s*, which he did not at first observe, would now occupy the same centre position; and, in order that the same spot as at first should still be observed on her centre, it would be absolutely necessary for her *to make a quarter rotation in a direction contrary to that of her revolution*." So far, however, is all this from being "evident" and "necessary," that it could only happen in the case, which he tacitly assumes without reason or proof, of the moon's moving in her orbit perfectly free from the action of a centripetal force; or, in other words, if the centripe-

tal force, or the earth's attraction of gravitation, were to act upon the moon's centre only, leaving her circumference, and all the other molecules of her mass between that and the centre, *free* to obey the impulse of the centrifugal or tangential force, which would, in that case, carry them all forward with the same velocity as the centre itself, and consequently all once round about that centre during the period of each orbital revolution. The changes, then, that would happen to his "remarkable spot S," would be really the effects, the signs, and the evidence of the moon's rotation, or turning round on her axis. Mr B., in common with other astronomers, has overlooked the very important difference that exists between the moon moving under the antagonist centrifugal and centripetal forces and an artificial body of the same form, a globe or a disk, which may be made to move in an orbit under the influence of the tangential force alone, perfectly free from any centripetal attraction. Such a body may be made to *shuffle* in a certain way round its orbit, presenting every point of its circumference to the centre of that orbit, *apparently* without rotating; but, even in that case, a real retro-rotation or backward-turning of the shuffling body on its own axis can easily be proved; and *without rotation*, either backwards or forward, the presentation of every point of its circumference to the centre of its orbit, or to a spectator within the periphery of the orbit, is perfectly impossible. On the other hand, were this artificial moving body to be subjected to a centripetal force, in the shape of a string, or other material vinculum, connecting any one point, or by two strings, or other material vincula, connecting any two diametrically opposite points of its circumference with the centre of its orbit, it would then, in every orbital revolution, necessarily and inevitably present, like the moon, the same face continually to that centre, without requiring any "quarter," or complete "rotation, in a direction contrary to that of its revolution."

Gravesande's illustration is this: "The effect of the moon's motion round her axis is, that she turns continually the same face to the earth. Suppose the moon in N (fig. 9); the face looking to the earth is mni . If the moon were not to rotate on her axis, and her individual particles were to move forward in parallel lines, the line mi would coincide with the line ln , in the moon's position B, and the hemisphere mni would coincide with lmn . But, seeing that while the moon describes the quarter of her orbit, she also accomplishes the fourth part of her rotation, the face which should coincide with lmn is in m, n, i ; that is, again looking to the earth T. In the same manner is it proved that the same face mni is seen by a spectator on the earth in the positions P and E." *Philosophiæ Newtonianæ In-*

stitutiones, &c. Leidæ et Amstelodami, 1728: pars i. cap. 7, p. 385. The noted particle *if* never occupied a more important place than here. Give all that he requires, and the conclusion of his argument would be correct. Refuse, and it falls to the ground at once. The moon does not rotate on her axis, nor do her particles move in parallel lines; they move in concentric ellipses. Another illustration substantially the same as this, is to show that a body moving along the diagonal of a square or parallelogram, would reach the end of the diagonal without turning round on its axis. So it would most certainly; but the propounders of that illustration, as well as M. Gravesande, forget, or overlook the fact, that the moon or other body revolving in an orbit has a certain thickness, and that the molecules of its mass describe different orbits of different dimensions in proportion to their distance from the orbit's centre, and that at *every angle* of the rhombus or four squares, which they make use of to illustrate the moon's orbital revolution and rotation, the point of the circumference *a*, in one with the radius-vector at starting, *is carried 90° away from the radius*, and that at each of these angles the direction of the line of motion is also changed 90°; and that these four changes of 90° each, make up a complete rotation of *a* round the axis, during the orbital revolution. In fact, the only substantial difference between the case of revolution in a circle, and revolution along the four sides of a square or a rhombus, is that in the former case, the rotation is performed gradually and imperceptibly, and in the latter only four times, to the amount of 90° at once. It is true, that in the latter case the rotation is effected by means of the axis being four times *drawn back*, away from the advanced point *a*; but the result is not the less precisely the same; for round about the axis *a* proceeds, and this is proved irrefragably by its assuming every varying degree of angular distance in its progress away from and back again to, the radius-vector facing the centre of the square. If the body were to stop at any angle, or in the middle of any side of the square, and turn once round on its axis, from east to west, while the square was carried past it in the same direction, it would exhibit all the phenomena of *parallelism*, associated with unquestionable rotation.

In the article *MOON*, in the Penny Cyclopædia, the author proceeds in the usual manner. "The discovery of the telescope, and the examination of the moon which followed, soon shewed that the planet always turns the same face towards the earth, or very nearly. *From hence it immediately follows that the moon must revolve round an axis in the same time as that axis revolves round the earth.* If any one should walk round a circle, without turning himself round, that is, *keeping his face always in the same direction*, he would present alternately his front and back

to the interior of the circle But, if he desires to turn his face always inwards, he must turn round in the same direction as he walks round." The logic here is the same as Mr Buchanan's, and is just a new version of the old fallacy, which I have already detected and exposed;—taking for granted, as an indubitable fact, what is nevertheless a physical impossibility,—the presenting of "every part of its circumference in succession" to the centre of its orbit, by a globe revolving in an orbit, *without rotating on its axis*. Our walking gentleman himself shall prove this. Let him be tied to the centre of his circle, as the moon is to hers by her centripetal radius of gravitation, and then let him walk round the circle, *if he can*, with his face constantly pointed in the same direction to a distant object outside. He will find the latter condition impossible unless he turn backward on his own axis, simultaneously with his forward orbital movement. Suppose him to be tied to his circle by a cord fixed round his waist. As he moves round his orbit he will find that the noose will make him keep the *same side*, or *face*, or *back*, as the case may be, directed constantly to the centre of the circle, unless he draw himself continually away from its knot and the radius-vector by moving "left shoulders forward." One of two things seems perfectly certain: either the noose and its knot revolve about the man, or the man turns backward on his own axis within the noose; but the knot being fixed to the radius, and the radius to the centre of the circle, it is quite obvious that they cannot revolve about the man, therefore it must be the man that retro-rotates within the noose. This has been abundantly shown already, and is just another version of the water in the basin. Let the walking gentleman turn round again on his own axis, in the direction of "right shoulders forward," within his noose, while going round his circle, and he will find his face and back and two sides, in turn, or, in other words, "every part of his circumference in succession," presented to the centre of the circle, thereby completely disproving the doctrine he was brought to prove, namely, that the moon's presenting the same hemisphere continually to the earth is the effect of her rotation on her own axis, from west to east, the same direction which the experimenter had last taken, in his turning round. The author of this cyclopædic article has just assumed that the same effect as would be produced by a person's moving first straight forward along a given line, and then moving straight backward to his starting point, would be produced were he obliged to go out of his straight path round some intervening obstacle, such as a round table placed upon the line. But, in the latter case, he would be obliged, in going from north to south, for instance, to shuffle out of his way to the left, and, in returning, to shuffle

again to the right, in order to get round about the obstacle. In making these shuffles, the opposite points of his own circumference *cross each other's paths*; because at every instant of progression the central axis of his body changes the direction of its line of motion, without the points of his circumference turning back in the same proportion, so as to occupy always their original places on the same side of the axis. This certainly does not happen when he moves straight forward and backward; and these crossings of the different orbits described by the different points of his own circumference are equivalent to, and precisely effect, one complete rotation on his own axis. All the parts of any horizontal section of his body move with the same velocity; and, to enable them to move through equal spaces in equal times, they must find room for their movement by some going to the outside, while others are falling back to the inside, of the orbit described by his perpendicular central axis; and the reason why he keeps his face always in the same direction, while he is really rotating, is that what his circumference gains by rotation in one direction is lost by his centre's moving forward in the opposite direction. Common sense might tell him this; but the string and the noose round his body confirm its dictates undeniably. The same would be the result of his shuffling along the four sides successively of a square, or a parallelogram, or a rhombus, with his face looking invariably in the same direction; north, or south, or east, or west, as the case might be. At each of the four corners, all the points of his body cross each other's paths horizontally: and, as before, these horizontal crossings amount to one complete rotation round his perpendicular axis. To make the experiment more complete, let him tie himself to the centre of his circle by a slack cord, simply attached to a button or button-hole of his vest, without a noose, and then shuffle round, with his face always looking in the same direction. When he completes his revolution he will find the cord drawn round about him. How could it get into such a position unless he had turned himself round on his own axis, and drawn it round along with that point of his outward man to which it was attached? It has not crept round about him of itself like a living serpent; yet has it been stretched out to the extent of a whole circumference of the moving body; a fact that, I presume, can only be accounted for by that body's having turned round on its own axis, and drawn the cord round about with it. Let him now, for a final experiment, just stop at any point of the circle, with his face to the centre, and the cord attached, as before, to his button or button-hole, and turn himself once round on his own axis, from east to west, or with his right shoulder backwards. The cord will be drawn round about him, and this

result will be admitted to be the effect of his retro-rotation. But, when precisely the *same effect* is produced gradually during an orbital revolution, what is so likely to produce it as the *same cause*, the revolving body's retro-rotation on its axis, in a direction *contrary* to that of the revolution performed by the axis itself?

The Marquis de la Place, in his "System of the World," translated by J. Pond, F. R. S, (the late Astronomer Royal,) Book i. ch. iv. p. 59—62, says, "The lunar disk contains a great number of invariable spots which have been observed and accurately described. They shew us that this body always presents to us very nearly the same hemisphere; it turns then upon itself in a period equal to its rotation round the earth, for if we imagine an observer placed at the centre of the moon, supposed transparent, he will see the earth and its visual ray revolve about him, and since this ray always intersects nearly the same point of the lunar surface, it is evident that this point must revolve round the spectator, in the same time, and in the same direction as the earth. Nevertheless, continued observation of the lunar disk has discovered some small diversity in these appearances; the spots are perceived to approach to and recede alternately from the limb; those that are very near the extremity appear and disappear successively by periodical oscillations, which have been distinguished by the name of the *libration of the moon*. To form a just idea of the principal causes of this phenomenon, we should consider that the disk of the moon, seen from the centre of the earth, is terminated by a great circle of the lunar globe, perpendicular to the radius drawn from this centre to that of the globe. It is upon the plane of this great circle that the hemisphere of the moon is projected, directed towards the earth, and its appearances arise from its *motion of rotation* relatively to its radius-vector: if it was without a motion of rotation this radius-vector would trace at every lunar revolution, the circumference of a great circle upon its surface, every point of which would be successively turned to us; but at the same time that the radius-vector traces this circumference, the lunar globe by its revolution brings always very nearly the same point of its surface to this radius, and consequently the same hemisphere towards the earth. The inequalities of the motion of the moon produce some small variations in the appearances, for the motion of rotation not partaking in a sensible manner of these inequalities, it is variable with respect to its radius-vector, which thus intersects its surface at different points. The lunar globe, therefore, makes, with respect to this radius, oscillations corresponding to the inequalities of its motion, which causes some part of its surface to be alternately concealed, and exposed to our observation. All these causes produce only an apparent libration of the lunar globe;

they are mere optical illusions, and do not affect its real motion of rotation."

It would scarcely be credible that this should have proceeded from such a man as La Place, were it not in perfect consistency with the prevalent opinions of astronomers on the subject of the moon's rotation. "An observer," he says, "placed at the centre of the moon, supposed transparent, *will see the earth and its visual ray revolve about him.*" The meaning of this passage is not very obvious; but probably it is this: The observer must be perfectly separate from, and independent of, the moon's mass, and capable of revolving about the earth unaffected by the moon's motion. In this case, says La Place, he might revolve without rotating, while the moon does rotate in the direction alleged, from west to east: and the result would be, that the same point of the moon's circumference, with the radius-vector and the earth's visual ray, or the earth herself, would appear successively on every side of the observer, or, as La Place says, would revolve about him. But the observer's apparent standing still in these circumstances is nothing else than that retro-rotation from east to west which has been mentioned so often; and the fact of his retro-rotation might be proved by attaching the observer by a cord to that point of the moon's circumference that is always in one with the radius. At the completion of his revolution the cord would be drawn round about him; and this could not have been occasioned by the radius revolving about him, for that is physically impossible. He will be placed in circumstances precisely similar to those of the walking gentleman, whose case we have so recently considered; and either gentleman might be very well represented by a thimble or a cork placed on the axis of the magnetic card of a marine compass carried round a circle. As the box revolves, with the same point of its circumference continually directed to the centre of the orbit, that point, with the centre itself and the radius-vector, will undoubtedly appear successively on every side of the gentleman's representative; not, however, because they revolve about him, which is impossible, but because he is continually turning himself round in a direction contrary to that which is taken by his own axis and the box that contains it, in performing their orbital revolution.

La Place adds, "since the earth's visual ray always intersects nearly the same point of the lunar surface, it is evident that this point must revolve round the spectator, in the same time, and in the same direction as the earth." So here we have a broad assertion of the proposition, that not only that point of the moon's circumference which remains in one with the radius-vector, but also the radius itself, and the earth which it represents, *actually revolve round about the moon's centre.* Such a re-

volution is just as impossible as it would be for a cannon ball to fly from earth to heaven, and again from heaven to earth and round about the stars, *without moving from the gun*. The earth never quits its position in, or near to, the centre of the moon's orbit; the radius-vector merely represents a certain point of the earth's circumference considered as expanded to the size of the orbit; and a certain point of the moon's circumference remains continually attached to the radius; how, then, is it possible, in the nature of things, that they can revolve round about a body, or point, or person that not only remains, as the moon's centre always certainly does, at a distance from, and to the outside of, the circle described by her inner point of circumference; but is also continually in motion round about the very objects—the earth, the radius, and the moon's attached point, that are said to revolve about it? The earth revolves about the moon's centre, but *without leaving its fixed place, in the centre of the moon's orbit*, at the very time the moon's centre is revolving about the earth. This is just the rod AB in one of its worst phases; and the very error committed by Galileo, when he thought he must have gone round about the water *if*, as he inferred, the water had not turned round on its axis. The earth, considered relatively to the moon, moves not at all; the nearest point of the moon, in one with the radius-vector, describes an orbit of 1,434,000 miles; while her centre, a thousand miles farther from the earth, describes an orbit 6000 miles larger, yet do both the earth, which never moves, and the moon's point which describes the smaller orbit, perform a revolution *round about the point which describes the larger orbit*, and which consequently remains invariably on the outside of them. How the earth, represented by the point A, and the radius-vector, represented by the body of the rod AB, could revolve about the moon's centre C, without the earth forsaking her fixed central position and crossing the moon's orbit twice, in going to the outside and returning, in the course of her circumgyration, far transcends my comprehension; and, were it not that such men as Galileo and Laplace have said it, I should scarcely have believed it possible for any human being to deliberately sanction and promulgate an opinion that seems so preposterous.

Laplace proceeds to say: "If the moon were without a motion of rotation, her radius-vector would trace, at every lunar revolution, the circumference of a great circle upon her surface, every point of which would be successively turned to us." I have shown already that this is impossible, and need not repeat my arguments and illustrations here. But, either he or his translator "brings" the absurdity to a climax when he says: "At the same time that the radius-vector traces this circumference, the lunar globe by its revolution brings always very nearly the same

point of its surface to this radius." So this great mechanician seems to have believed it possible for a radius-vector that remains always positively attached to the same point of a globe, to describe a circle all round the globe's circumference, without ever leaving or stirring from the point to which it is so attached. For "at the same time that the radius traces the circumference," the globe itself, moving apparently in the same direction, "brings always very nearly the same point of its surface to this radius." This means in plain English, that the radius *never* describes any circle at all round the moon's circumference, *because* the same point of circumference remains always attached to it, and will not allow it to set out on its circumferential journey, which in consequence is never made.

Far be it from me to think of disparaging the fair fame of Laplace; but, in this case, he seems to have been very greatly mistaken. Whether, however, the mistake lie with him or with me, and, whether or not I have made out the point I have been contending for, I shall now leave it to the public to determine, and the determination may be made very easily, for the demonstration is grounded on the following simple questions: 1. Is it possible for a ball, fixed on the point of a rod or stick, to turn round on its axis while it remains so fixed? 2. Is it possible for a wheel moving along a rail to turn round on its own axis, and at the same time keep the same point of its circumference continually in contact with the rail? 3. Is it possible for a rod or stick to turn round on both of its two ends at once? or to turn round on its middle while one end is held fast? Is it possible for a cord, attached by one end to the centre of a circle, and having its other end attached to the surface of a globe or wheel, either revolving round the circle, or remaining stationary at one point, to be drawn round about the circumference of the globe or wheel, unless that body turn round on its axis? To these questions I answer No; but the astronomical doctrine I have been combating requires all the answers to be in the affirmative. Which of us is right?

J. L.

Edinburgh, 18th March 1847.

CORRIGENDUM.

P. 11, line 34, *after* degree, *insert*—"of its circumference, while moving through one degree."